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FRICTION AND LUBRICATION,

DETERMINATIONS OF THE LAWS
AND COËFFICIENTS OF FRICTION BY NEW METHODS
AND WITH NEW APPARATUS.

BY

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PUBLISHED BY
THE RAILROAD GAZETTE, 73 BROADWAY, NEW YORK.

1879.

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ROBERT H. THURSTON.

Evening Post Steam Presses 208 Broadway, N. Y.

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PREFACE.

The lectures from which the following monograph is condensed, have grown out of an attempt to comply with the request of the Committee of the Master Car-builders Association to present the well-known facts, and others that had been determined by the lecturer relating to the subject, in a lecture at the rooms of that association in New York, December 20th, 1877.

An abstract of the lecture then given appeared in the *Railroad Gazette* of January 18th, 1878 (Vol. X, p. 23). See also *Johnson's Universal Cyclopædia*, Ont., Friction.

Since that time this investigation has been resumed, and the experimental work since accomplished in the Mechanical Laboratory of the Stevens Institute of Technology is here given, the whole presenting, it is thought, a complete *résumé* of existing knowledge on this, to the engineer, most important subject. The more recent determinations have been, in some cases, published in papers read before the American Association for Advancement of Science and the American Institute of Mining Engineers, 1878.

LIST OF ILLUSTRATIONS.

FIGURES. PAGE.
1. Hydrometer 66
2. Oleometer 66
3. Fire-Test Apparatus—Tagliabue 73
4. " " " 73
5. " " —Millspaugh 75
6. " " —Bailey 77
7. Bailey's Nasmyth Apparatus 87
8. McNaught's Oil-Test Apparatus 113
9. " " " 113
10. Napier's " " 114
11. Bailey's Ingham and Stapfer Machine 116
12. " Endurance Test 117
13. " " " for Railroads 118
14. Crossley's Dynamometer 119
15. Bailey's Pendulum Apparatus 120
16. Hodgson's Testing Machine 123
17. " " " 124
18. " " " 123
19. Thurston's " " Section 131
20. " " " Perspective 132
21. " Railroad " Section 146
22. " " " Perspective 146

CONTENTS.

ART. PAGE.
1. Friction defined........ 9
2. Rolling Friction—Coulomb's experiments........ 9
3. Morin's Experiments on Carriages........ 10
4. Later Experiments........ 11
5. Resistance of Railroad Trains........ 13
6. " " on Curves........ 16
7. Friction of Cordage........ 18
8. Journal Friction........ 18
9. Fluid Friction........ 19
10. Measurement of Friction........ 20
11. Amonton's Experiments........ 24
12. Morin's Experiments........ 24
13. Morin's Coëfficients of Friction of Motion........ 26
14. Rennie on Friction and Abrasion........ 26
15. Coëfficients of Friction of Rest........ 27
16. Abrading Friction........ 28
17. Friction of Brakes and Rails........ 29
18. Friction with Lubrication........ 34
19. Friction of Belts........ 34
20. Friction of Pump Pistons........ 37
21. Friction of Journals........ 37
22. Friction of Mill Shafting........ 40
23. Lubricants........ 41
24. Lubrication—Characteristics of Unguents........ 43
25. Value of a Lubricant........ 45
26. Kinds of Lubricants in Use........ 47
27. Purification of Oils........ 54
28. Limits of Pressure........ 55
29. Size of Journals........ 56
30. Methods of Oiling Journals........ 57
31. Methods of Testing Lubricants........ 59
32. Identification of Oils........ 60
33. Chemical Methods—Composition of Oils........ 61
34. Classification of Unguents........ 61
35. Alteration of Composition........ 62
36. Detection of Copper and Lead........ 63
37. Mixtures of Oils........ 64
38. Oleometry........ 65
39. Specific Gravity of Oil........ 68

40. Table of Specific Gravities.. 69
41. Densities of Mineral Oils.. 70
42. Equivalent Densities and Specific Gravities........................ 70
43. Rousseau's Diagnometer.. 71
44. Effect of Heat upon Unguents.. 72
45. Fire-Tests of Mineral Oils—Congelation........................ 72
46. Tests with Acid.. 79
47. Impurities of Mineral Oils.. 80
48. Oleography—Cohesion Figures.. 81
49. Gumming and Drying of Oils.. 85
50. Chemical Tests of Oils.. 89
51. General Methods of Analysis.. 90
52. Chateau's General Reactions.. 91
53. Preparation and Use of Re-agents.. 92
54. Reactions.. 94
55. Method of Using Tables of Reactions........................ 105
56. Machines for Testing Lubricants.. 111
57. Metcalfe's Experiments.. 125
58. Thurston's Apparatus and Experiments........................ 128
59. Description and Theory of the Machine........................ 130
60. Determining Lubricating Quality; Steam Cylinder Lubrication..... 136
61. Gumming and Endurance.. 140
62. Thurston's Railroad Testing Machine........................ 145
63. Earlier Researches.. 149
64. Thurston's Experiments and Researches........................ 155
65. " Tables for Low Pressures.. 156
66. " Method Illustrated.. 158
67. Friction, with Varying Pressure.. 173
68. " of Greases.. 177
69. " " Quiescence.. 178
70. " with Varying Velocity.. 180
71. Table of Coëfficients—Pressure, Velocity and Temperature Varying... 185
72. Friction, with Varying Pressure and Speed........................ 187
73. " " " Pressure, Speed and Temperature........... 187
74. Endurance of Wearing Power.. 193
75. Commercial Value of Lubricants.. 200
76. Application of Figures Obtained.. 205
77. Conclusions from Thurston's Results........................ 208

LECTURES

ON

Friction, Lubrication and Lubricants.

1. FRICTION is a resistance which is always met when two bodies or particles, whether solid, liquid or gaseous, are compelled to move, one upon another. There are three kinds of friction, so called; rolling and sliding with solids, and fluid friction with liquids and gases. These are all governed by different laws, and with each, the statements of those laws, as usually given in the text-books, probably require some modification.

2. ROLLING FRICTION.—Coulomb was the first to determine the law of rolling friction, and he found that, so long as the wheel or roller and the surface on which it rolled were not injured, the resistance was proportional to the weight, and diminished as the diameter of the wheel increased.

Coulomb and others have, as will be shown at greater length presently, found $R=f\frac{W}{r}$, in which

R is the resistance applied at the *circumference* of the wheel, W the total weight, r the radius of the wheel, and f a coëfficient which is very variable and equal to as much as 0.06 for wood and 0.005 for metal.

When the pressure becomes so great as to crush the fibres of the wood, the friction is increased irregularly, and cannot be estimated with any degree of accuracy.

Experiments, similar to those made by Coulomb in 1781, have been also made by General Morin at the Conservatoire Des Arts et Métiers, Paris, in which oak rollers nine inches in diameter were used under small loads, and rolling upon poplar rails, Morin also concluded the resistance to be proportional to the pressure and inversely as the diameter of the roller. Expressed algebraically, $R=f\frac{W}{r}$, as before; but he also found that the resistance increased with diminishing bearing surface.

With a bearing of 0.656 feet, or 9 inches, and loads of 350 to 450 pounds, the value of f was found to average 0.002874; with bearing of a total width of 0.081 feet, or ten inches, and loads of 375 to 450 pounds, the value was $f=0.006374$.

3. The same laws were found by Morin, about 1840, to be applicable to vehicles with little modification. He states:

1. On pavements and macadamized roads, the resistance is proportional to the total weight of load and vehicle, is inversely proportional to the diameter of wheel, and is independent of the breadth of the tire. It increases with the velocity.

2. On soft ground the resistance decreases with increase of breadth of tire, and is unaffected by the speed of the vehicle.

3. The line of draught should be horizontal.

The conclusions relative to rolling resistance on hard roads are also applicable to railroads.

It follows that wheels should be made as large as possible,* and the breadth of bearing as great as is needed to prevent crushing of the material. Morin found four-wheeled carts to be preferable to those having a single pair of wheels.† The value of f for wagons was, on soft soil, about 0.065, or 14½ lbs. per ton—but under very favorable conditions, became as low as $f=0.02$, or 4½ pounds per ton, which value may be taken for the friction of motion on smoothly paved and macadamized roads.

4. Later experiments upon more modern forms of vehicles give results as follows:

M. Dupuit finds the resistance to hauling wagons on macadamized roads to be directly proportional to the total weight, inversely as the square root of the diameter of wheel, and unchanged by variations of either speed or width of tire. On paved streets the resistance increases at such high speed as give rise to concussions, and is diminished by increasing the breadth of tire.

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* Mr. Joseph Coe made wheels for heavy carts, about 1850, six feet in diameter, and worked them satisfactorily.

† *Vide* "Expériences sur la Tirage des Voitures," etc., A. Morin, 1842.

Debauve (1873) found the resistances on macadamized roads to vary from 70 pounds per ton for heavy carts, to 80 for carriages, and from 40 to 80 on paved streets, for the same classes of vehicles.

Tresca found the resistance of an omnibus to be, at ten miles an hour, 80 to 85 pounds per ton on macadamized roads, and 65 or 70 on paved streets.

The draught of heavy wagons becomes as high as 0.10,—224 lbs. per ton—and usually is not far below 0.07—about 150 pounds per ton, on soft ground, as in fields.

A committee of the Society of Arts reported a loaded omnibus to exhibit a resistance * on various roads, of:

Pavement.	Speed.	Resistance.
On Granite paving	2.87 miles	17.41 lbs. per ton.
" Asphalte	3.56 "	27.14 "
" Wood	3.34 "	41.60 "
" Macadam. graveled	3.45 "	44.48 "
" " granite, new	3.51 "	101.09 "

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* See Clarke's "Manual for Mechanical Engineers," 1877.

Clarke deduces, from published experiments, the formula—*

$$R = 30 + 4v + \sqrt{10v}.$$

in which the resistance, R, is given in pounds per ton, the velocity v being taken in miles per hour, and the road being assumed to be well macadamized. The same authority states that a good Flemish draught-horse will work at the rate of about 22 ton-miles per day in summer, and 28 in winter, averaging 25 for the year.

5. THE FRICTIONAL RESISTANCE OF RAILROAD-TRAINS is principally rolling friction, the sliding friction of the axle journals in their bearings forming a small proportion of the total resistance, under good working conditions. A railroad train in good order, and on a good road, will not be safe against starting under the action of gravity alone, unless the gradient is less than 18 or 20 feet to the mile; once started, it will continue in motion on gradients as low as 13 feet per mile. Under the latter conditions, and at the low speed due to so slight a decline, axle and flange friction may probably be neglected. The coëfficient of rolling friction for trains in good order is therefore $\frac{13}{5280}$, or nearly 0.0025, equivalent to one-quarter of one per cent. or less than 6 pounds per ton.

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* "Manual," p. 964.

This latter figure is the minimum usually taken by engineers in estimating the resistance of trains, inclusive of axle and flange friction.

This part of the rolling resistance is the same at all velocities.

The resistance at starting, as above, is seen to be greatly in excess of the rolling friction during motion. It is composed in a greater degree of the journal friction, and has, as its measure $\frac{20}{5280}=0.0038$, or about $\frac{3}{8}$ of one per cent., equivalent to $8\frac{1}{2}$ pounds per ton.

The resistance of a locomotive is much higher than that of the train, and is taken at 0.005—one-half per cent., or about 12 pounds per ton, and this includes the resistances due to the motion of its machinery.

Rolling friction is usually overcome by an effort applied at the axis of the wheel or roller, as in cars, wagons, &c., but sometimes by a force applied at the circumference. In the latter case, the "moment," or leverage of the applied force is greater, and its required intensity correspondingly reduced to one-half the former.

Where journals are carried on friction-rollers, the rolling friction thus introduced is added to the total resistance; but the sliding journal friction is reduced nearly in the proportion of the diameters of the friction-rollers to the diameters of the journals of the latter. The total *work* of friction, which is the product of the resistance into the distance through which that resistance is overcome, is thus often greatly reduced. In cases in which the frictional resistance is increased, there will still be an economy of power, if the work of friction can be, at the same time, lessened in a greater proportion.

The resistance on railroads, under average conditions, and including all forms of resistance, is given by Clarke as:

For train only, . . $R=6+\frac{v^2}{240}$.

For engine and train, $R=8+\frac{v^2}{171}$.

On street railroads, the resistances of the cars are greater and sometimes four times as great as on railroads. Hughes found, on an English "tram-way" a resistance of 26 pounds per ton.

These frictional resistances are sometimes on railroads greatly increased by the resistance of the air, which as "head resistance," amounts —in lbs. per square foot of front exposed—to 0.005 of the square of the velocity in miles per hour with which the air meets the head of the train. Side winds often increase the flange resistance seriously, and thus greatly add to the power required in hauling trains.

The following table gives a résumé of the coëffiecients of rolling friction; *i. e.*, it gives values of f for the formula $R = f\frac{W}{r}$, in which R is the resistance, W the total weight, and r is the radius of the wheel or the roller.

KIND OF ROAD.	VALUE OF f.
Newly laid sand or gravel	0.067
Stony, in ordinary condition	0.05
Well paved	0.02
Hard, smooth ground	0.02
Well macadamized and rolled	0.015
Smooth wooden pavement	0.01
Ordinary railroads	0.003
Well laid railroad track	0.002
Best possible railroad	0.001

6. THE RESISTANCE OF TRAINS RUNNING ON CURVES has been studied more recently by Mr. S. Whinery, who deduces for total resistance the following formula :*

$$R = D\frac{(g + l)}{25} + a\,n,$$

in which R is the total resistance, D the degrees of curvature, g the gauge of the track, l the length of rigid wheel base and a and n are quantities expressing resistances due to accidental and irregular conditions.

The resistance is inversely as the radius of curvature, directly as the load, and nearly independent of the velocity.

---

* "Trans. Am. Soc. C. E.," April, 1878.

The amount of elevation of the outer rail should be, according to Whinery:

$$E = 4.9 \frac{\dfrac{V^2}{32.2\,R}}{\sqrt{1 + \dfrac{V^4}{1{,}036.8\,R^2}}}$$

This amounts to 6 inches for a 10° curve, at 30 miles an hour, or for a 3° curve at 60 miles on standard (4′ 8½″) gauge. For 60 miles and a 11° curve, the elevation becomes two feet.

At 25 miles per hour, the resistance is increased by curvature about 0.4 pound per degree and per ton.

Chanute* thus analyzes this increase of resistance:

Due to	twist of wheel	0.001
"	slip "	0.1713
"	flange friction	0.2450
"	loss at couplings	0.0213
	Total	0.4386

Loose wheels reduce this loss 20 or 25 per cent. The rigid form of wheel-base of European cars and locomotives doubles the increase due to curves, as well as increases the resistance on the straight line. The "coning" of wheels somewhat increases the resistance—according to Chanute, from 0.12½ to 0.25 pound per degree of curve and per ton.

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* "Trans. Am. Soc C. E." April, 1878.

7. The friction, so-called, of cords, or more properly, the resistance due to the rigidity of flexed cords or ropes, where used on pullies and on the sheaves of pulley-blocks, may best be considered here, although it is not a kind of true friction.

The theory of this kind of resistance, which ascribes it to the rigidity of the cordage, is too complicated to be given here. An approximate value is given by the following formulas, in which R is the resistance in pounds, T the tension on the unrolling part of the cord, d the diameter of the cord in inches, and D that of the pulley:

$$\text{For hempen rope, } R = 0.65\ T\frac{d^2}{D}$$

$$\text{For wire rope, } R = 1.5\ T\frac{d^2}{D}$$

8. JOURNAL FRICTION.—In all ordinary cases, as of journals in well-lubricated bearings, the friction probably combines both the other forms of resistance, and, consequently, the laws of friction, as determined by experiment upon journals and as affecting journals are quite different from the laws of friction of solids which are almost universally enunciated in hand-books and text-books.

In fact, as will be presently seen, the resistance of journals revolving in their bearings not only follows a law which is widely different from that given in standard works, but, at usual speeds and pressures, the amount of that resistance may be found to differ immensely from that indicated in engineering and mechanical hand-books which have hitherto appeared.

Combining, as is probable, both forms of frictional resistance, it would therefore seem evident that the laws of friction of journals should include both methods of variation of resistance, and the wide variation of the facts ascertained by experiment from those predicted by the commonly asserted, but, as here applied erroneous, so-called laws of friction.

9. FLUID FRICTION is found to vary with the square of the velocity, and is proportional to the area of rubbing surface, and is probably independent of the pressure. In hundreds of experiments with pressures varying from 5 to 275 pounds to the square inch, I have found the friction of well lubricated journals to vary in such a manner as to prove that the law which governs such cases is quite different from that which applies with dry solids, and have thus found the deduction above given confirmed. When a lubricant is interposed between the rubbing surfaces of a revolving journal and its bearing, or between a sliding plane surface and its support, if acting effectively, it forms a fluid cushion

separating the surfaces more or less perfectly as it is more or less viscous, and as capillarity is greater or less, thus giving the resistance to motion more or less of the character of fluid friction. Thus the same surfaces lubricated with the same material may, under light pressure, exhibit a resistance varying approximately according to the law of fluid resistance, and, under comparatively heavy loads, it may be governed more nearly by the laws of friction of solids. Under intermediate pressures its behavior will be of intermediate character.

10. THE COËFFICIENT OF SLIDING FRICTION as ordinarily stated, or *the ratio of frictional resistance to the total pressure* holding two sliding solids in contact, which is the usual measure of friction, varies directly as the pressure, and is independent of the velocity of motion and of the area of the surfaces in contact.

The "friction of quiescence," or the resistance to starting the two bodies into relative motion, is greater than the "friction of motion;" but it is subject to the same laws. The law just stated is subject to limitation. It becomes untrue when the pressure is so great as to produce a depression, or to abrade the rubbing surfaces.

The friction becomes greater than is indicated by the stated law when the pressure becomes so low, also, that the resistance is principally due to the viscosity of the interposed liquid, and then follows an entirely new law. Between these limits the resistance due to friction between solid *lubricated* surfaces is of a mixed nature.

There are two usual ways of measuring friction, and of determining the coëfficients for solids, which are described in the books:

First.—Place the two bodies in such a position that the rubbing surface shall be horizontal; load the upper one to the proposed extent and then apply a measurable force to produce motion, either by means of a weight or a spring balance. The weight of the uppermost piece with its load makes up the quantity P, and the applied force is F. The "coëfficient" of friction is the ratio of these quantities, and we have $f - \frac{F}{P}$. This value f may be less than one per cent., or it may be fifty per cent., according to the nature of the materials and their condition as respects lubrication.

The other method is equally easy of application. Lay the one solid on the other and tilt them up until the upper will slide on the lower. The tangent of the angle is the coëfficient of friction, and we simply measure the height of a point in the surface on which sliding occurs, and the horizontal distance of the vertical from a point in the same surface which lies on a level with that to which this height was measured, and the division of the former by the latter measurement gives the value of the coëfficient of friction.

Under ordinary conditions the engineer or the physicist calculates the resistance due to sliding friction as he does that of rolling friction, by multiplying the total sliding weight by a "coëfficient" or factor, the value of which has been determined for certain general cases, by experiment.

In illustration of the use of the coëfficient of friction, it need only be said that the multiplication of the measure of load or pressure in any case by the coëfficient, gives the measure of the force resisting sliding; the division of the measure of the latter, when known, by the coëfficient, gives the measure of the magnitude of the pressure or the load.

That the tangent of the inclination of a plane on which a body free to move will just start into motion, and that the tangent of the angle at which sliding occurs at a uniform velocity, measure respectively the values of the coëfficients for rest and for motion, is thus shown:

Let a=the angle.
W=the weight carried.
R=the pressure between the two surfaces.
f=the value of the coëfficient.

Then the resistance of friction measured parallel with the surface of the inclined plane will be fR, and we shall have:

$$fR - W \text{ Sin. } a = 0$$
$$R - W \text{ Cos. } a = 0$$

Whence:

$$f \text{ Cos } a - \text{ Sin. } a = 0 \text{ and } f = \text{Tan. } a.$$

The two following propositions will illustrate the mathematical application of the principles of friction:

1. To determine the limiting values of P to W, fricting acting up or down the plane, when P represents the effort exerted on the sliding body and W is its weight.

Since there exists an equilibrium of forces, where W acts vertically downward, R acts perpendicularly to the surface of the inclined plane, and P acts in any given direction, making an angle β with the surface of the plane, we shall have for the maximum:

$$P \text{ Cos. } \beta - fR - W \text{ Sin. } a = 0$$
$$P \text{ Sin. } \beta + R - W \text{ Cos. } a = 0$$

Whence: $$P = \frac{W(\text{Sin. } a + f \text{ Cos. } a)}{\text{Cos. } \beta + f \text{ Sin. } \beta.}.$$

For a minimum value, we get:

$$P \text{ Cos. } \beta + fR - W \text{ Sin. } a = 0$$
$$P \text{ Sin. } \beta + R - W \text{ Cos. } a = 0$$

And $$P = \frac{W(\text{Sin. } a - f \text{ Cos. } a)}{\text{Cos. } \beta - f \text{ Sin. } \beta}.$$

11. The earliest to experiment in this important field was Amontons, who published, in 1699, in the memoirs of the old Academy of Sciences, values which took a coëfficient of about 0.33, or one-third, when the rubbing surfaces are coated with lard, a value which is far too high for ordinary work. Coulomb, a French officer of engineers, and a member of the Institute, reported experiments* in 1781, which were more complete and more accurate, and in which he determined both the friction of rest and that of motion. He states that the friction is proportional to the pressure, and independent of the extent of surface and of the velocity of rubbing, and proves that the friction of rest is greater than that of motion.

12. The most complete series of experiments ever made were, however, those of General Morin. Although made from 1831 to 1834, they are still quoted as standard, by nearly all text-books and works on engineering.† The apparatus consisted of a box, which could be loaded at pleasure, sliding on a bed and moved by a weighted cord passing over a pulley at the end of bed. The pull was measured and registered by a recording dynamometer, attaching the cord to the box, which furnished graphic representations of all the variations of frictional resistance. The curves thus described were

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* "Morin's Mechanics;" p. 261, New York, 1860. † *Vide* "Recueil des Savants Etrangers," Vols. IV and V.

parabolas, proving, for the small pressures and for the speeds adopted that the friction was constant and independent of the velocity. It was found proportional to the pressure and independent also of the area of surfaces. The same law, as respects pressure and area of surface, held in the determinations of the friction of rest.

The slightest jar was found often sufficient to reduce the friction of rest to that of motion. Fatty unguents were found to diminish the amount of friction without changing the law; water proved to have no value as a lubricant. Friction during shock was, so far as could be determined, subject to the same laws. The pressures adopted in these experiments were all very low, and therefore gave exceedingly high values of the coëfficient of friction—values which are rarely attained in engineering practice.

THE "ANGLE OF FRICTION," the "angle of repose," or the "limiting angle of friction," as it is variously termed, is that angle of which the tangent is the coëfficient of friction. It measures the inclination from the horizontal at which the sliding body would just start on a smooth plane, or would just retain motion once acquired, according as the coëfficient is that of rest or of motion. Friction is sometimes measured by the use of an inclined plane so arranged that this angle can be measured.

13. Coëfficient of Friction.—The following table gives the value of the coëfficients as given by standard authorities:

Material.	Condition of Surfaces.	*f*.	Friction Angle.
Brick on limestone	Dry	0.67	33° 50′
Cast-iron on cast-iron	Slightly greased	0.16	9° 6
“ on oak	Wet	0.65	33° 2′
Copper on oak		0.17	9° 38
Copper on oak	Greased	0.11	6° 17′
Leather on cast-iron		0.28	15° 39′
“ “	Wet	0.38	20° 49
“ “	Oiled	0.12	6° 51′
Leather on oak	Fibres parallel	0.74	36° 30′
“ “	“ crossed	0.47	25° 11′
Oak on oak	Fibres parallel, dry	0.62	31° 48′
“	“ crossed, dry	0.54	28° 22′
“	“ parallel, soaped	0.44	23° 45′
“	“ crossed, wet	0.71	35° 23′
“	“ end to side, dry	0.43	23° 16′
“	“ parallel, greased	0.07	4° 6′
“	Heavily loaded and greased.	0.15	8° 45′
Oak on pine	Fibres parallel	0.67	33° 50′
“ limestone	“ on end	0.63	32° 15′
“ hempen cord	“ parallel	0.80	38° 40′
Pine on pine	Fibres parallel	0.56	29° 15
“ oak	“ “	0.53	27° 56′
Smooth granite on rough granite		0.66	33° 26
Stone on dry clay		0.51	27° 2′
“ wet clay		0.34	18° 47′
Wrought iron on oak		0.62	31° 48′
“ “	Wet	0.65	33° 2′
“ on wrought iron		0.28	15° 39
“ on cast iron		0.19	10° 46′
“ on limestone		0.49	26° 7′
Wood on metal	Greased	0.10	6° 0
Wood on smooth stone	Dry	0.58	30° 7′
“ “ earth	“	0.33	18° 16′

14. G. Rennie, experimenting in 1829, determined some facts which do not appear in Morin's reports. He concludes:*

1. The laws of sliding friction differ with the character of the bodies rubbing together.

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* “Philosophical Transactions:” 1829, p 169.

2. The friction of fibrous materials is increased by increased extent of surface and by time of contact, and is diminished by pressure and speed.

3. With wood, metal and stones, within the limit of abrasion, friction varies only with the pressure, and is independent of the extent of surface, time of contact, and the velocity.

4. The limit of abrasion is determined by the hardness of the softer of the two rubbing parts.

5. Friction is greatest with soft and least with hard materials.

6. The friction of lubricated surfaces is determined by the nature of the lubricant, rather than by that of the solids themselves.

Experimenting with cloth, Rennie found the resistance to starting to vary with time of rest from one-third to even more than the total weight. Increase of surface produced great increase in the angle of repose.

15. The following table gives values of the coëfficient of *friction of rest* for loads on the metals up to the limit of abrasion:

FRICTION OF REST.

PRESSURE.		VALUES OF *f*.			
Pounds on Sq. Inch.	Kilog. on Sq. Meter.	W't Iron on W't Iron.	Wrought on Cast Iron.	Steel on Cast Iron.	Brasss on Cast Iron.
186⅔	131,220	0.25	0.28	0.30	0.23
224	157,460	0.27	0.29	0.33	0.22
336	236,200	0.31	0.33	0.35	0.21
448	314,932	0.38	0.37	0.35	0.21
560	393,664	0.41	0.37	0.36	0.23
672	472,396	abraded.	0.38	0.40	0.23
784	551,128	"	abraded.	abraded.	0.23

16. ABRADING FRICTION.—After abrasion begins, the coëfficient rises as the pressure increases. The pressure at which this increase begins to be observable is as low as 8 pounds per square inch with pure tin.

Rennie, using tool steel, found it to abrade at a pressure of 10 tons per inch. He remarks that the hardening property of steel and its great power of resisting abrasion make it superior to all known metals for use in delicate instruments, as in pendulums and balances, where these properties are essential.

The same experimenter, among other researches, determined the friction of ice upon ice, finding it to vary from 12½ per cent. under a pressure of one ounce per square inch down to 1⅔ per cent. where the pressure rose to 9 pounds. After sixteen hours contact, the friction was unchanged at the lower limit, but became 4 per cent. under the higher pressure. The friction of steel skates was 4 per cent. at a pressure of two pounds per square inch, but only 1½ per cent. at 200 pounds.

17. FRICTION OF BRAKES AND RAILS.—The most instructive experiments upon the friction of unlubricated metals under heavy pressures are probably those obtained on railroads by the use of continuous brakes. The data which are perhaps most commonly used in estimating the adhesion of engines are those given in Molesworth's Pocket Book, which are as follows:

ADHESION PER TON (OF 2,240 LBS.) OF LOAD ON THE DRIVING WHEELS.

When the rails are very dry	600 lbs.	per ton.
" " " wet	550 "	"
In ordinary English weather	450 "	"
In misty weather, if the rails are "greasy"	300 "	"
In frosty or snowy weather	200 "	"

If these figures are used, it will be found that practically a locomotive will, at slow speed and under favorable circumstances, pull a heavier load, and that at high speeds it will not pull as much as the figures show that it should—a consequence of the now ascertained fact that the resistance is affected by speed, as well as by pressure and by temperature, A series of experiments were made on the Paris & Lyons Railroad "with a wagon, presumably having four wheels, of which the brake was screwed up, so that the wheels were skidded." The resistance to traction or the friction on the rails, at various velocities, was as follows:

EMPTY WAGONS. 3.40 tons.	STATE OF THE RAILS.			
	Dry.	Very Dry.	Damp.	Dry and Rusty.
Velocity of wagon. Miles per hour.	Coëfficient of Friction. Weight = 1.	Coëfficient of Friction. Weight = 1.	Coëfficient of Friction Weight = 1.	Coëfficient of Friction. Weight = 1.
9 to 14	0.208	....	....	0.201
14 to 18	0.179	0.246	....	0.182
18 to 22	0.167	....	0.110	0.175
22 to 30	....	0.222	....	0.162
30 to 40	0.144	0.202	....	....
40 to 50	....	0.187	0.083	0.136

From these experiments it will be seen that the friction with a dry rail at a speed of 9 to 14 miles per hour is equal to a little more than one-fifth of the load, while at 30 to 40 miles per hour it is little more than one-eighth."*

The following table shows the result obtained by Captain Galton and Mr. Westinghouse by the sliding of the wheel on the rail, that is, steel tire and steel rails:

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* "Railroad Gazette," Sept. 20, 1878.

AVERAGE SPEED. Miles per hour.	COËFFICIENT OF FRICTION at commencement of experiment to 3 seconds.
10	0.110
15	0.087
25	0.080
38	0.047
45	0.051
50	0.040

From these two tables it will be seen that the results obtained differ very widely, and that the coëfficients given by Poirée are almost twice as great as those given by Captain Galton. In one respect, however, they are both agreed, which is that *the friction diminishes* very rapidly *as the speed increases.*[*]

By applying the coëfficients given in the two preceding tables and calculating the adhesion of locomotive wheels, and placing the results in the form in which Molesworth gives them, we would have the following table, in which the coëfficients given in the second column of Poirée's table are employed in making the calculation.[†]

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[*] "Railroad Gazette," Sept. 20, 1878.

[†] The coëfficient for a speed of 22 to 30 miles per hour and for 40 to 50 miles per hour not being given in this column, the approximate quantities 0.156 and 0.133 have been used in the calculations.

Adhesion per Ton (2,240 Lbs.) Load on the Driving-Wheels:

From Poiree's Data.		From Galton and Westinghouse.	
Speed in miles per hour.	Adhesion.	Speed in miles per hour.	Adhesion.
9 to 14	465.9 lbs. per ton.	10	246.4 lbs. per ton.
14 to 18	400.9 " "	15	194.8 " "
18 to 22	374.0 " "	25	179.2 " "
22 to 30	349.4 " "	38	127.6 " "
30 to 40	322.5 " "	45	114.2 " "
40 to 50	297.9 " "	50	89.6 " "

The results given by Poirée's data at the slow speeds do not differ very widely from the data as given by Molesworth.

The Galton-Westinghouse experiments also show that the friction of brake-shoes on the wheels follows the same law that governs the friction of the wheels on the rails.

The following table shows the more important results:*

Average Speed.		Coëfficient of Friction between Cast-Iron Brake-Blocks and Steel Tires of Wheels.			
Ft. per sec.	Miles p. hour.	1st 3 seconds.	5 to 7 sec.	12 to 16 sec.	24 to 25 sec.
7	5	0.360	....	....	....
14	10	0.320	0 209	....	....
35	20	0.205	0.175	0.128	0.070
43	30	0.184	0.111	0.098	....
58	40	0.134	0.100	0 080	....
65	..	....	....	...	....
73	50	0.100	0.070	0.056	....
88	60	0.062	0.054	0.048	0.043

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* "London Engineering." Aug 23 1878.

The coëfficient with wrought-iron shoes at 18 miles per hour was 0.170, at 31 miles 0.129, at 48, 0.110; being somewhat less than with cast-iron, but the difference is not so very marked.

Captain Galton concludes a recent paper by saying that "it may be assumed as an axiom that for high velocities a brake is of comparatively small value unless it can bring to bear a high pressure upon the surface of the tire almost instantaneously, and it should be so constructed that the pressure can be reduced in proportion as the speed of the train is reduced, so as to avoid the sliding of the wheels on the rails."†

His conclusions are thus summarized:

1. The application of brakes, when a "skidding" of the wheels does not occur, does not seem to reduce their rate of rotation.

2. Skidding occurs immediately when their velocity is reduced below that due to the speed of the train.

3. Resistance is *reduced* by "skidding" the wheels.

4. The pressure required to produce skidding is greater than that needed to hold the wheels while skidding.

5. The pressure of the brake-blocks must be proportional to the coëfficient of friction.

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† "Railroad Gazette."

18. FRICTION WITH LUBRICATION.—Rennie and Morin both made experiments upon the frictional resistances of lubricated surfaces, and some of the results obtained by the latter have already been given in the table. They have comparatively little value in consequence of the adoption of light pressures only. Morin remarked that unguents, under heavy pressures, and when the surfaces were at rest, were expelled, causing the friction of starting greatly to exceed that of rest, and that the comparatively great effort required to start machinery was thus accounted for.

19. THE FRICTION OF BELTS was found by Morin to be unaffected by width of belt, by the arc embraced, or by the diameter of the pulley—in other words, of the area of surfaces in contact. He found it proportional to the angle subtended by the belt at the surface of the pulley and to the logarithm of the ratio of the tensions on the two sides:

$$f = \frac{\log. \frac{T}{T^1}}{1.363}$$

In his experiment, he obtained, for belts in good order $f = 0.282$ when dry and $f = 0.377$ when wet.

The following is a summary of his figures:

VALUE OF *k* IN PRONY'S FORMULA $T - kT^1$.

Proportion of Circumfer'ce in Contact.	New Belt on Wooden Pulleys.	Ordinary on Wood.	Belts on Iron.	Wet Belts on Iron.	Rope on Wooden Axles.	
					Rough.	Smooth.
0.20	1.9	1.8	1.4	1.6	1.9	1.5
0.40	3.5	3.3	2.0	2.6	3.5	2.3
0.60	6.6	5.9	2.9	4.2	6.6	3.5
0.80	12.3	10.6	4.1	6.8	12.3	5.3
1.00	23.1	19.2	5.8	10.9	23.9	8.0
1.50	....	....	....	....	111.3	22.4
2.00	....	....	....	....	535.5	63.2
2.50	....	.. .	....	....	257.48	178.5

The maximum difference of tension allowable becomes:

$$D = T - T^1 = (k -, 1)\, T^1.$$

The minimum tension allowable to prevent slip is taken as:

$$T^1 = \frac{T + T^1}{2} = \frac{1}{2} \frac{k + 1}{k - 1} D.$$

The maximum stress allowable on the leather was stated at about 350 pounds per square inch of cross-section.

In the equations—

$$R = T - T_2 = T_1 (1 - e^{f\theta}) = T_2 (e^{f\theta} - 1),$$

$$\frac{T_1 \times T_2}{2R} = \frac{e^{f\theta} + 1}{2 (e^{f\theta} - 1)},$$

f varies from 0.15 to 0.6, the former value being found only where the belt is actually wet with oil.

In designing, Reuleaux takes $f = 0.25$ and the experiments of Messrs. Towne and Briggs[*] indicate that this value is exceeded, under ordinary working conditions, more than 60 per cent.

The angle $\Theta = 2\pi n$, where n is the number of turns or part of turns taken by the belt about the pulley. Rankine gives[†] the following values of the coëfficient $2.7288 f$ in the equation $e^{f\Theta} = 10^{2.7288fn}$ which comes into use in the application of these formulas :

$f =$	0.15	0.25	0.42	0.56
$2.7288 f =$	0.41	0.68	1.15	1.53

and, where $\Theta = \pi$ and $n = \frac{1}{2}$, as is usual,

$T_1 \div T_2 =$	1.603	2.188	3.758	5.821
$T_1 \div R =$	2.66	1.84	1.36	1.21
$T_1 + T_2 \div 2R =$	2.16	1.34	0.86	0.71

Usually we assume $T_2 = R$, $T_1 = 2R$, $T_1 + T_2 \div 2R = 1.5$ and f becomes 0.22.

†Rankine gives f for a wire rope running on cast-iron at 0.15 and on gutta-percha at 0.25.

Clark gives[‡] the following table based on the work of Mr. H. R. Towne, and taking the working stress on the belt at $66\frac{2}{3}$ pounds per inch in width for single belts.

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[*] "Journal of the Franklln Institute," 1868. [†] "Machinery and Mill work," p. 352. [‡] "Manual for Mechanical Engineers," p. 750.

Driving Power of Leather Belts.

Arc of Contact.	Stress on the Belt per Inch.	Horse-power transmitted per inch in width.		Sum of Tension per 1 Inch.	Press. on Pounds per 1 Inch.
		At 1 ft. per Second.	Per ft. Diam. and per Rev.		
90°	32.33	0.059	0.00308	101.00	71.42
100°	34.80	0.063	0.00331	98.53	75.47
110°	37.07	0.067	0.00353	96.26	78.85
120°	39.18	0.071	0.00373	94.15	81.53
150°	44.64	0.081	0.00425	88.69	85.67
180°	49.01	0.089	0.00467	84.32	84.32
210°	52.52	0.095	0.00500	80.81	78.05
240°	55.33	0.100	0.00527	78.00	67.59
270°	57.58	0.105	0.00548	75.75	53.56

India rubber belting has three times the adhesion of the leather belt, while it has a strength of about 200 pounds per inch of width as commonly made.

20. THE FRICTION OF PUMP-PISTONS has been determined by d'Aubuisson, and found to be directly porportional to the diameter of the pump and to the pressure.

The friction of hydraulic-press plungers has been found by Hicks to be very nearly, when well designed and in good order, twenty per cent. divided by their diameter in inches; a four-inch plunger offering a resistance of five per cent., and a twenty-inch press one per cent. of the total load.

21. THE FRICTION OF JOURNALS has been studied by Rennie and by Morin, and recently

by many engineers. The following are the figures given by Morin. They are to be compared with those to be presently given as derived from later experiments, and may be taken as representing maximum values for new journals and comparatively small loads. The journals were from two to four inches in diameter, and loaded with from 330 pounds to 2 tons.

FRICTION OF JOURNALS IN MOTION.—MORIN.

MATERIALS.	LUBRICANTS.	COËFFICIENT OF FRICTION. LUBRICATION.	
		Intermittent.	Continuous.
Cast-iron on cast-iron	Oil, lard, tallow	0.07 to 0.08	0.03 to 0.054
	" and water	0.08	
	Asphalte	0.054	
	Unctuous	0.14	
	" and wet	0.14	
Cast iron on bronze	Oil, lard, tallow	0.07 to 0.08	0.03 to 0.054
	Unctuous	0.16	
	" and wet	0.16	
	" (slightly)	0.19	*
	Dry	0.18	†
Cast iron on lignum-vitæ	Oil, lard	....	0.090
	Unctuous (oil or lard)	0.10	
	" (lard and graphite)	0.14	
Wrought-iron on cast-iron	Oil, lard, tallow	0.07 to 0.08	0.030 to 0.054
Wrt.-iron on bronze	Oil, tallow, lard	0.07 to 0.08	0.030 to 0.054
	Unctuous and wet	0.19	
	" (slightly)	0.25	‡
Iron on lignum-vitæ	Oil, lard,	0.11	
	Unctuous	0.19	
Bronze on bronze	Olive oil	0.10	
	Lard	0.09	
Bronze on cast-iron	Oil, tallow	....	0.030 to 0.054
Lignum-vitæ on cast iron	Lard	0.12	
	Unctuous	0.15	
Lignum-vitæ on lignum-vitæ	Lard	....	0.07

* Wear began. † Wood slightly greasy. ‡ Wear commenced.

These experiments were not only confined to comparatively low pressures, but the pressures actually used per unit of area of surface are not specified. The dynamometer used was that of Morin, with which the assumption then made, that the flexures of the spring were proportional to the load, is incorrect; the flexure increases more rapidly than the load. The figures given for f are therefore considered unreliable.*

As early as 1831, Nicholas Wood determined the coëfficient of friction on old well-worn axles, under conditions not fully specified, to be about 0.02. Later German experiments, with pressures of 200 to 250 pounds per square inch, gave, at 230 revolutions, $f = 0.00891$ to $f = 0.013$, and it was concluded that these values could be reduced. Still later experiments showed an increased resistance in higher ratio than increase of load, and an increase with increase of velocity, while experiments at Hanover lead to the conclusions that, under loads of from 320 to 1,250 pounds on the journal, the coëfficient for iron axles lubricated with rape-seed oil and running in white metal bearings is 0.009 to 0.0099; that with gun-bronze bearings the figure becomes 0.014; that the value is independent of the weight of load within usual limits;

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* "Carnet de l'Ingénieur."

that the area of the journal does not affect the resistance; that resistance is independent of velocity of rubbing; that grease gives a higher figure than oil for light loads, but the same under heavy loads.*

22. THE FRICTIONAL RESISTANCE OF MILL-SHAFTING has been determined by the very numerous and extended experiments of Mr. Samuel Webber. The pressures are here not very high, and Webber's values for the coëfficient of friction average very nearly the same as the figures obtained by Morin. They are, for intermittent lubrication, 0.066, and for continuous oiling, 0.044. Morin obtained 0.075 and 0.042.

Clark obtains formulas for the work of friction and the horse-power absorbed by shafting, using $f = 0.070$ and $f = 0.043$ for one revolution.

Work $= U = 0.0182\,Wd$, for ordinary oiling.

" $= U = 0.0112\,Wd$, " continuous "

$$H.P. = \frac{0.0182\,WdS}{33{,}000} = \frac{Wd\,R}{1{,}800{,}000} \text{ for ord. oiling.}$$

$$= \frac{0.0112\,Wd\,S}{33{,}000} = \frac{Wd\,R}{2{,}950{,}000} \text{ for contin. oiling.}$$

in which W = the total load, d = diameter of journals, R = revolutions per minute.*

The coëfficient determined by Webber varies from 0.033 to 0.055, or from one-thirtieth to one-twentieth, with continuous lubrication, and from 0.052 to 0.114, or from one-twentieth to one-ninth for ordinary lubrication.

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* W. R. Browne, "Railroad Gazette," Aug. 16, 1878. † "Manual," p. 763.

23. LUBRICANTS.—From what has been stated, it is seen that the amount of frictional resistance to the motion of machinery is determined by the character of the lubricating material. It thus happens that all recent experiments in this field have been made in investigations of the value of lubricants, which investigations include very much more than a single measure of the coëfficient of friction; and the later determination of the friction of lubricated surfaces at the various pressures and speeds which are commonly met with in modern machinery, will therefore be given after discussing the nature of lubricating materials, and the standard or other methods of ascertaining their value. The tables to be hereafter given will serve the mechanic, the engineer or the designer of machinery as data by means of which to estimate the probable losses of power by friction, under almost every set of conditions met with in practice.

The value of a lubricant, *as* a lubricant, is entirely independent of the market price, except so far as the demand of consumers of unguents affects the market. Some of those materials which would be most useful in reducing friction, could they be so applied, are entirely unknown to consumers of lubricating substances, because of their monopoly for other purposes, for which they are in such demand as to entirely remove them from a market in which other unguents can be obtained at such comparatively low price as to throw the former quite out of competition in the oil market. The best known lubricant for general purposes—sperm oil--is far less used than the less excellent, but cheaper, lard oil, which, in turn, is less generally used than the mineral and mixed oils with which the market is always largely supplied.

The effect of friction—rolling as well as sliding —is to wear and abrade solids, and, with fluids as well as with solids, to generate heat to an amount which is the exact equivalent of the work of friction, and which, could it be all collected and measured, would be found to be a precise measure of the power wasted and lost in consequence of the friction. The amount of heat thus produced is equal to one British "thermal unit."* for each 772 foot-pounds of work expended in overcoming friction. This figure is that known as Joule's "mechanical equivalent of heat." Where the work is measured by the metric system, this corresponds to the development of one "*calorie*"† of heat for each 424 kilogrammeters of work done in overcoming frictional resistance.

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* A British thermal unit is the quantity of heat required to raise the temperature of a pound of water one degree Fahrenheit.

† The metric "*calorie*" is the heat required to raise the temperature of a kilogramme of water one degree Centigrade.

This evolution of heat has a serious ill effect in several ways: it reduces the viscosity of lubricants, thus rendering them more liable to exude from between the rubbing surfaces at high pressures; it is cumulative, and causes danger to become more and more imminent as it progresses beyond the limit within which conduction and radiation may dispose of it to surrounding objects as fast as generated; it causes serious injury to the surfaces in contact, cracking, distorting and abrading them, and thus increasing the friction while destroying journals and bearings; it often even ignites the lubricant, overheating, softening and weakening the abrading metals and endangering all combustible material in its neighborhood. The journals of machinery are often actually welded into their bearings. The burning of mills and of steam-vessels and the breakage of car-axles, and consequent destruction of trains loaded with passengers, sometimes result from the use of improper lubricants or of badly proportioned rubbing parts.

24. LUBRICATION has for its objects, therefore, both the reduction of friction and the prevention of excessive development of heat, and the engineer resorts to this expedient of inter-

posing between the rubbing surfaces a substance having the lowest possible coëfficient of friction and the greatest capacity for preventing or reducing the development of heat. It is evident, then, that, in order that any substance may be efficient as a lubricating material, it must possess the following characteristics :

1.—Enough "body," or combined capillarity and viscosity, to keep the surfaces between which it is interposed from coming in contact under maximum pressure.

2.—The greatest fluidity consistent with the preceding requirements, *i.e.*, the least fluid-friction allowable.

3.—The lowest possible coëfficient of friction under the conditions of actual use, *i. e.*, the sum of the two components, solid and fluid friction, should be a minimum.

4.—A maximum capacity for receiving, transmitting, storing and carrying away heat.

5.—Freedom from tendency to decompose or to change in composition by gumming or otherwise, on exposure to the air or while in use.

6.—Entire absence of acid or other properties liable to produce injury of materials or metals with which they may be brought in contact.

7.—A high temperature of vaporization and of decomposition, and a low temperature of solidification.

8.—Special adaptation to the conditions as to speed and pressure of rubbing surfaces, under which the unguent is to be used.

9.—It must be free from grit and from all foreign matter.

25. THE VALUE OF A LUBRICANT to the consumer, as is seen from what has been just stated, depends on its cost in the market, its efficiency in reducing friction, its durability under wear, its freedom from liability to "gum," its freedom from acid and from grit, and its permanence of composition and of physical condition when subjected to changes of temperature, and also, frequently, its capacity for carrying away heat from journals already heated.

Thus, sperm oil is known by all experienced mechanics and by all dealers in oil, to be one of the very best of known lubricants; but its high price precludes its use, except for special purposes. Some other oils are cheap, but have little lubricating power; still others are good reducers of friction, but do not wear well, or frequently cannot be retained on the journals; others, as linseed and the drying oils, generally, although sometimes excellent otherwise, gum so seriously that they cannot be used for lubrication; while a good deal of the tallow in the market and some other lubricants, contain acids of decomposition, or acids which have been used in their clarification, which have not been so completely removed as to prevent injury by their action on the metals. Some lubricants cannot be used at low temperatures, because they are liable to congeal, and others cannot be used in steam cylinders or where high temperature is liable to be met with, because they decompose or vaporize under such circumstances.

Every dealer in oils and every consumer of lubricants who desires to know with certainty whether he has, in any case, precisely that lubricant and that quality which is nominally given him must resort to some method of identification of the material. Every user of such a material who desires to know whether it is well adapted to a specific purpose, or who wishes to find out what are its peculiar characteristics, must find some method of testing it, and of thus ascertaining whether, under the conditions arising in his practice, it will serve his purpose. He must know whether it will bear the pressure, and will run without heating his journal at the speed to which he must subject it.

Many different conditions must, therefore, be studied, and the behavior of the lubricant determined with reference to each before it can be known, with any degree of certainty, what is its real value for any specified purpose, and it is equally evident that the conditions under which the behavior of an oil or other lubricating material is to be determined should always be those approximating with the greatest possible exactness to the conditions proposed in its actual use.

26. Lubricants are sometimes solid, but usually liquid, and of the liquid unguents there are many varieties in the market which differ in their viscosity and cohesiveness as widely as they do in nearly every other quality, and range from the most liquid and water-like watch-oils to those "heavy-bodied" and densest of all the oils—castor oil and rosin oil. We have semi-solid lubricants, of which tallow, soap and wax are illustrations, and still others are perfectly hard and solid, as graphite, soapstone.

The engineer also uses what are known as "anti-friction metals," one of the oldest and best known of which is the so-called "Babbit-metal." These are permanently fixed in the bearings in the form of linings, and their peculiar use is to present to the journal, instead of the hard unyielding and resistant surface of the metal itself, a material which more readily and perfectly adapts itself to the form of the journal which it supports.

Lead has been introduced by Mr. Hopkins to act thus temporarily, gradually, as it wears, letting the journal down to a good bearing on the brass of the boxes.

Metaline and some other anti-friction metals are used without lubricants, and are, therefore, themselves, as truly lubricants as are plumbago and similar solid materials which are usually finely ground and interposed between rubbing surfaces.

In some cases no lubricant will suffice to keep a journal from heating and even "cutting;" in such an event the "brasses" are sometimes made hollow and a stream of water is made to circulate through them, thus effectually keeping them cool.

In the "*Palier-glissant*" of Girard and the "Water-bearings" of Shaw, the journal is supported upon a cushion of water which is forced into a space in the journal beneath it by a pump, and at such a pressure that the journal is perfectly "water-borne" and revolves on the liquid cushion. Shaw has applied this plan successfully in supporting vertical shafts.

The most generally applied fluid lubricants are the better known and cheaper kinds of animal, fish, vegetable and mineral oils; of these sperm stands admittedly at the head of the list, lard, neats-foot, whale, tallow, seal and horse oils are all largely used either alone or mixed. The vegetable oils in use are olive, which is by far most generally used in other countries; cotton-seed oil in the United States, palm, rape-seed, oleine, colza, poppy, peanut, rosin, cocoanut and castor oils* are all more or less employed in lubrication. Of the fish oils, porpoise, blackfish, cod and menhaden† oils are most used. The mineral oils are of two general classes: the shale oils, obtained from certain shales, and the petroleums, which come from extensive oil lakes, situated, usually, far beneath the surface of the earth, and which are principally supplied by the oil wells of Pennsylvania and other of the United States.

Of these oils, sperm is still largely used, notwithstanding its high price, since it excels nearly all others in its power of reducing friction and immensely excels them in endurance. Rape-seed is, in some districts, now displacing olive oil as a lubricant, but the mineral oils, pure or mixed, are rapidly taking the leading place in all markets. Scotland is producing 25,000,000 gallons of shale oil from 800,000 tons of shale, of which oil 10,000,000 gallons are illuminating oils and the remaining products include 10,000 tons of lubricating oil, 6,000 tons of parafine wax, and also 2,500 tons of ammonium sulphate. The petroleums are found in China, India, Italy and other parts of the world;

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* Linseed oil is a good reducer of friction, but dries and "gums" too rapidly to permit its use as a lubricant.

† The whale is not a fish, but an animal classed among the mammals.

the island of Trinidad contains a lake of petroleum—" Pitch Lake "—the shores of which are composed of bitumen, produced by its evaporation and oxidation. But the greater part of the petroleum of the world is produced in Pennsylvania, West Virginia and Ohio. Pennsylvania alone has produced in a single year—1874—over 10,000,000 barrels, of which one-half was exported to Europe and used largely for lubrication, but far more generally in illumination.

The greases, or semi-fluid lubricants, are sometimes used in their natural state, as tallow, lard, wax and other similar substances and sometimes are made up artificially, *e. g.*, the various kinds of soap. Mixtures of tallow and black-lead, white-lead and oil, and other mixtures containing sulphur, are often used.

For some special purposes, certain mixtures are used, as, for cooling hot journals, mixtures of oil and of white or black lead, oil and sulphur or greases composed of oil to which some alkaline water has been added. I have, in my experience with very large and troublesome marine engines, found sulphur and oil on the journal, with the application—very cautiously—of cold water externally, to work best.

For a railroad grease I think a mixture of equal parts of tallow and palm oil, with water to which ½ pound of caustic soda to the gallon has been added, a good one, mixing them pretty warm. Two parts parafine, one of lard and three of lime-water is said to be a good grease, too, especially for heavy, slow-moving journals.

A mixture of eight parts of bayberry wax with one of graphite is very good, also.

Grease is usually employed in lubricating axle-journals in Great Britain, and is generally of palm oil. The following are said to be good compositions* for that climate:

RAILROAD AXLE GREASE.

	For Summer.	For Winter.
Tallow	504 lbs.	420 lbs.
Palm Oil	280 "	280 "
Sperm Oil	22 "	35 "
Caustic Soda	120 "	126 "
Water	1,370 "	1,524 "

On German railroads the following composition is used;

	Parts.
Tallow	24.60
Palm Oil	9.80
Rape-seed Oil	1.10
Soda	5.20
Water	59.30
	100.00

The following is Austrian:

	Tallow.	Olive Oil.	Old Grease.
For Winter	100	20	13
For Spring and Autumn	100	10	10
For Summer	100	1	10

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* W. R. Browne. "Railroad Gazette," Aug. 9, 1875.

The solid lubricants are often found to work well when no fluid will answer at all. Some of them sustain immense pressures without injury, Those in general use are certain metallic compositions, mixtures of metallic with non-metallic elements—graphite, sulphur, soapstone, asbestos, lampblack, and white lead (carbonate of lead). In some cases they are permanently and solidly fixed, as already stated, and sometimes are applied, at intervals, between the rubbing surfaces, as are the oils.

The most widely known of the former class is "metaline," a material of a composition which is variable, and is determined by the conditions to which it is to be subjected. It is made, usually, by grinding the various ingredients to an impalpable powder, mixing them according to certain definite formulæ, which are the direct result of experiment, and subjecting the mass to immense hydraulic pressure in chilled steel molds. Erom these last the metaline emerges in the form of a short rod or plug, from one-eighth to five-sixteenths inch in diameter, in condition either soft enough to be readily dented by the nail, or sufficiently hard to require a knife to cut it; also in all intermediate stages. It looks like black-lead, but is more unctious, and somewhat lighter in color, To insert it, the box or gib, for example, is bored with shallow holes, these being made with a square-ended bit, in order to leave a flat bottom. Their depth is about three-sixteenths of an inch. Into these the metaline is inserted, the diameter of the plugs being sufficient to insure a tight fit, and the surface is smoothly reamed off. Such a preparation often reduces friction, and prevents serious heating or abrasion, while presenting the, in some cases, very great advantage of freedom from the objections which are peculiar to, and inseparable from, the use of oil or other grease.*

Plumbago is used generally by interposition, although sometimes forming an ingredient in the composition of anti-friction and "anti-attrition" compounds of the first class. It should always be absolutely pure and free from grit, and should be ground to the condition of a flaky powder.† At least one engineer expresses a decided preference for soapstone powder, in the form of dust, as a lubricant for the axles of machines. For this purpose it is first reduced to a very fine powder, then washed to remove all gritty particles, then steeped for a short period in dilute muriatic acid, in which it is stirred until all particles of iron which it contains are dissolved. The powder is then washed in pure water again to remove all traces of acid, after which it is dried, and is the purified steatite powder used for lubrication. It is not used alone, but is mixed with oils and fats, in the proportion of about 35 per cent. of the powder added to paraffine, rape or other oil, or the powder may be mixed with any of the soapy compounds employed in the lubrication of heavy machinery.* These materials are now much used in making up packing for the "stuffing-boxes" of steam engines, &c.

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* "Iron Age." † "American Machinist," Nov., 1877, p. 3.

27. PURIFYING OILS.—Oils which have been once used should be carefully cleansed before being again applied to bearings. Some one advises the following as a good method of purifying lubricating oil: A tub holding 63 quarts has a tap inserted close to the bottom, and another about four inches higher. In this receptacle are placed 7 quarts boiling water, 3½ ounces carbonate of soda, 3¼ ounces chloride of calcium, and 9 ounces common salt. When all these are in solution, 45 quarts of the oil to be purified are let in and well stirred for five or ten minutes; the whole is then left for a week in a warm place, at the expiration of which time the clear, pure oil can be drawn off through the upper tap without disturbing the bottom.

Dr. Dotch communicates to the "Scientific American" the following method and proportions for refining crude cotton-seed oil: 100 gallons of the crude oil are placed in a tank, and 3 gallons of caustic potash lye, of 45° Baumé, are gradually added and well stirred for several hours; or the same quantity of oil is treated with about 6 gallons of soda lye, of 25° or 30° Baumé, and heated for an hour or more to about 200° or 240° Fah. under constant stirring, and left to settle. The clear yellow oil is then separated from the brown soap stock, and this dark soap sediment is placed in bags, where the remainder of the oil will drain off; and the sediment has a marketable value of 3 or 4 cents a pound to soap-makers. The potash lye has to be made in iron pots, but the oil and lye may be mixed in wooden tanks.

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* "N. Y. Sun."

28. THE PRESSURE *which can be permitted* upon rubbing surfaces is determined by the velocity of rubbing, the character of the lubricant, and the nature of the surfaces themselves. The two surfaces should usually differ—the one being hard enough to bear the maximum pressure without change of form, and the other being less hard, in order that it may not abrade the first. With such an arrangement, the surfaces, if properly cared for, take a fine, smooth, mirror-like polish and give a minimum frictional resistance. Cast-iron surfaces are usually less satisfactory than good wrought-iron, and homo-

geneous and moderately soft steel is vastly better still. A pressure of 800 pounds to the square inch can rarely be attained on wrought-iron at even low speeds, while 1,200 pounds is not infrequently adopted on the steel crank-pins of steamboat engines. I have known of seven to nine thousand pounds pressure per inch being reached on the slow-working and rarely moved pivots of swing bridges. In my own practice I never, if I can avoid it, use higher pressures than 600 and 1,000 on iron and on steel, and, for general practice, make the pressure less as the speed is greater, since the amount of heat developed is directly a measure of the amount of work done in overcoming friction, and is proportional to the speed as well as to the pressure.

29. SIZE OF JOURNALS.—By a comparison of the behavior of the journals of the engines of naval steamers in 1862 I determined the following formula for the size of journals for such engines and for stationary steam-engines:

$$l = \frac{PV}{60,000d}.$$

in which l is the length of the journal in inches, P the load in pounds, and V the velocity of rubbing in feet per minute; d is the diameter in inches. Rankine published, in 1865, the following as applicable to locomotive practice;

$$l = \frac{P(V+20)}{44,800d.}$$

These are intended for iron journals; those of steel may sometimes work well if of one-half the length given by the formulas.

The length being known, the pressure per square inch admissible is:

$$p = \frac{60,000}{V} \quad \text{(Thurston)}$$

$$p = \frac{44,800}{V+20} \quad \text{(Rankine).}$$

Where journals are exposed to dust, as in locomotives, it is advisable to make them of greater length than where they are fully protected. This difference is observed in the two formulas just given. The best makers of mill-shafting make the journals about four diameters long.

30. OILING JOURNALS.—It is evident that the method of supplying the lubricant has an important influence on the economy of its use, A perfectly uniform supply of the minimum safe quantity enables an economy to be attained which is surprising to one who has not measured the quantity of oil used. Some years ago a distinguished firm of tool builders told me that the hangers of their line shafting were working perfectly with but 34 drops of oil each per week.

I have often used a wire bent into syphon shape and loosely wound with lamp wick in the old fashioned oil cups. A little experimenting determines just how many strands of wick should be used and just how low the oil can be permitted to run down in the cup. and the minimum expenditure is thus reached.

The later cups of Dreyfus and others are, if properly fitted, similarly economical. My syphons were always removed when the engine was stopped for any length of time, to prevent expenditure of oil when it was not needed. Another good arrangement for very large and important journals is an oil-pump taking oil from a reservoir into which it returns from the journal. Self-oiling boxes are still another and a more familiar device.

From what has already been said, it is seen that what is a good lubricant for one purpose is not necessarily good for another. Water is valuable on the lignum-vitæ sheath in the stern-bearing of the screw-shaft of a steamer, or on the wooden step of a turbine water-wheel, and answers an excellent purpose in the "*palier-glissant;*" and it is the best substance known to absorb and convey away heat; but it is not a true unguent, and could not be used as such on ordinary journals.

Plumbago, tallow and castor oil have the "body" needed for extremely high pressures; and sperm oil is the best known lubricant for general purposes; hut only an oil having the purity and limpidity of watch oil will answer for watch work. The heavy oil would produce too great resistance by its viscosity to be suitable for light work, and the watch oil would be unable to sustain the pressure in heavy work.

With oils of little "body," the greatest care should be taken to secure perfect regularity of supply and to feed the least amount consistent with safety. Heavier oils should be fed more rapidly, and tallow and the greases are usually supplied as fast as the journal will take them.

31. THE MODERN METHODS OF TESTING OILS are directed to the determination of a number of independent facts. These objects are;

1.—Their identification and the detection of adulteration.

2.—The measurement of density.

3.—The determination of their viscosity.

4.—The detection of tendency to gum.

5.—The determination of temperatures of decomposition, vaporization and ignition.

6.—The detection of acidity.

7.—The measurement of the coëfficient of friction.

8.—The determination of their endurance, and their power of keeping the surfaces cool.

32. IDENTIFICATION.—It is some time sufficient for the user of an oil to identify it and to be able to detect adulterations. Sperm and lard oils, for example, are standard lubricants; and if the consumer or dealer can assure himself that the oil which he has in hand is pure sperm or pure lard, that is often enough, since long experience may have taught him that this oil, and no other, is likely to fully answer his purpose. Cases do sometimes occur in which the purchaser of an oil does not care to try if other less well known oils may not meet his wants quite as well and at lower cost.

The tests for identification are chemical and physical. The chemist can sometimes, by applying "re-agents," which have peculiar effect on an oil, determine whether that oil is sperm, or lard, or other, and detect adulterations. This is, in some cases, quite easy to do and tolerably certain; since there are usually very few oils of which the cost would be low enough to permit their use as adulterants. For example, the chemist would look for cotton-seed oil, perhaps, in his tests of so-called *pure* lard oil, since that, in the present condition of the market, is about as likely to be used as an adulterant of lard as any other oil. This kind of test would rarely be used, except by an expert chemist, and it is enough to describe a few of the best known.*

33. CHEMICAL METHODS.—Professors Crace-Calvert, Cailletet, Chateau, Waltz, and many other chemists have systematically studied the reactions of oils with various chemicals with a view to their identification and the detection of adulteration.

MM. Chevreul and Braconnot (1813) were probably the first to determine with satisfactory accuracy the composition of fatty substances. They found them to be thus composed:

ANIMAL.			VEGETABLE.		
	Mazarine.	Oleine.		Mazarine.	Oleine.
Mutton tallow	80	20	Colza oil....	46	54
Beef tallow..	80	30	Olive oil.....	28	72
Lard........	38	62	Almond oil...	24	76

Chevreul and T. de Saussure determined the elementary composition of several of these bodies thus;

	Carbon.	Hydrogen.	Oxygen.
Sheep's fat........................	79.0	11.7	9.3
Lard............................	79.0	11.1	9.8
Human fat........................	79.0	11.4	9.6
Nut oil..........................	77.9	10.5	9.1
Almond oil........................	77.4	11.5	10.8
Linseed oil........................	76.0	11.3	12.6
Olive oil..........................	77.2	13.3	9.4

34. CLASSIFICATION.—These fatty unguents are divided into five classes:

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* See the treatise of Theodore Chateau: "Guide Pratique de la Connaissance et de l'Exploitation des Corps Gras Industrielles." Paris. 1864.

1. Oil, which is liquid at ordinary temperatures.
2. Butter, or thicker oil.
3. Tallow,
4. Grease.
5. Wax.

All have great commercial and industrial value; but the oils are far the most commonly useful.

35. ADULTERATION OF OILS.—The composition and character of these substances may be changed in several ways. They may absorb oxygen from the air and become rancid; they may dry away leaving a kind of varnish—like olive oil—or they may simply thicken, or gum, and lose their fluidity as well as their property of burning, as in their natural state, without smoke. These changes are prevented by the exclusion of the air.

They may also take up metals, when inclosed in metallic vessels, and thus become modified in character.

Dr. Stevenson Macadam states that in the course of a lengthened series of experimental observations on various paraffine oils his attention was directed to a certain oil which burned somewhat imperfectly in different lamps. It was feared that this oil was contaminated largely with lead compounds, which choked up the wick and ultimately diminished its capillary attraction so much that the light was extinguished. In a single night the wick of the lamp had to be changed several times, and the wicks when charred left a fine net-work of lead. The oil had been stored in a tank lined with lead, and dissolved so much of the lead that its value as a luminant was destroyed. The action of the oil on tin, copper and iron was so slight that its luminant properties were not much diminished. Zinc, however, was much affected, and the oil was consequently rendered nearly as useless for illuminating purposes by it as by lead. Dr. Macadam therefore suggests that, while the vessels for the retention of paraffine oil may be safely constructed of or be lined with tin, copper or iron, it would be preferable to use cisterns lined with enamel for storing the oil. William Watson, in a paper recently read before the British Association, describes the results of his experiments on the above subject. He finds that of all the oils examined, paraffine and castor oil have the least action on copper, and linseed and olive oil the greatest; sperm and seal oil have but a very slight action.

36. DETECTION OF COPPER AND LEAD.—To detect the presence of copper, mix a small portion of the oil with twice its weight of nitric acid in a test-tube and shake well, then, separ-

ating the acid from the oil, add ammonia to the former; if copper is present the reaction will give a blue color by the formation of an ammoniacal solution of that metal.

To detect lead, add to a portion of the oil, contained in a test-tube, a small quantity of sulphuric acid, of carbonate of soda, or of caustic soda; if lead is present, the solution will become white and will yield a precipitate of similar color; to insure certainty, add to the solution caustic soda until the acid, if used, is neutralized, or of acid, if soda has been used, a few drops of sulphur solution, the presence of lead will be indicated by a dark brown precipitate; with bichromate of potassium or the iodide of potassium, a yellow precipitate is found.

To test lubricating oil for acid, dissolve a crystalized piece of carbonate of soda about as large as a walnut in an equal bulk of water, and place the solution in a flask with some of the oil. If, on settling after thorough agitation, a large quantity of precipitate forms, the oil should be rejected as impure.

37. MIXTURES.—Good oils are adulterated by the addition of cheaper oils. These adulterations are detected by changes of density, or of freezing point, by differences produced in temperature on the addition of concentrated sul-

phuric acid, and by the reaction produced by the addition to the oil of various chemical reagents, and, finally, by the sense of touch, taste and smell.

The latter method presupposes great familiarity with and experience in the use of oils, and can be practiced with satisfactory results, usually, only by experts. Some oils are, however, are so characteristic in taste and odor that a novice may readily recognize them. It is always best to compare the suspected oil with a sample of known purity. The characteristic odor of an oil can be brought out more strongly by warming it. The taste, odor and feeling of the oil are sometimes considerably modified by the locality whence it is obtained, by the season during which it is prepared, and by the method of manufacture.

38. OLEOMETRY.—The first of the physical tests, which tests precede chemical analysis, is the determination of density. This is, perhaps, the simplest and easiest method of identifying a standard oil, although by no means a certain one. This may be done by carefully weighing an exactly measured volume of the lubricant and comparing its weight with the standard volume of a standard substance, or by the use of the "densimeter," or oleometer. This little instrument, generally known as the hydrometer, takes its name from

the application for which it has been designed, as, for example, lactometer when used to determine the density of milk, and alcoholometer when used to measure that of alcohol.

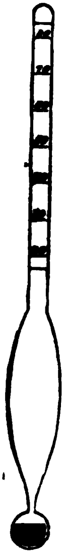

Fig. 1.

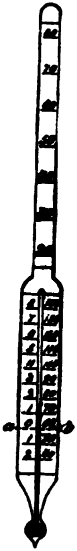

Fig. 2.

It is a glass cylinder (fig. 1) about ¾ or ⅞ inch in diameter and 4 or 5 inches long, having at one end a bulb loaded with shot, and at the other a small cylindrical stem suitably graduated, Placing this instrument in a liquid, it floats upright, with the loaded end downward, and sinks to such a depth that the figure on the stem reads the density or the specific gravity (the terms are not precisely synonymous) of the liquid.

In using this instrument the liquid must usually have the standard temperature, say 60 degrees, as its density is considerably affected by heat or cold. Another form of hydrometer is that shown in fig. 2, which has a thermometer attached to the lower end. This is intended to assist in making corrections for a temperature above or below 60 degrees. When the thermometer indicates a temperature above 60, which is shown by the figure on the right side, the corresponding number opposite must be added to the indications on the scale above. If the thermometer stands below 60 degrees, the corresponding number opposite must be deducted.

The specific gravity of any substance is proportional to its density, and is the ratio of the weight of a given volume of the substance to that of an equal volume of water, both being taken at the temperature of maximum density of the latter. The density may also be measured by any other standard. These oleometers are often—in fact, usually—graduated by the system of Beaumé, in which $\frac{140}{130+\text{Beaumé}}$ = specific gravity, and $\frac{140}{\text{sp. gr.}} - 130 = \text{B}^\circ$, the reading of Beaumé.

Now, determining the gravity of an oil, sperm, for example, and finding it to be 0.8750, or 30° Beaumé, it would be at once concluded to be impure; because sperm should give about 0,8810 or 0.8815, corresponding to 29 B.

There are many forms of the oleometer, nearly all, however, having the same general character.

39. SPECIFIC GRAVITY OF OIL.—The more accurate method of determining specific gravity by weighing on the chemist's balance has been frequently adopted.

A standard temperature is usually adopted and all results reduced to standard by first determining the coëfficient of expansion, which, for pure olive oil, has been determined by Mr. C. M. Stillwell to be 0.00063 for 1° Centigrade or 0.00035 per degree Fahrenheit.

Oils often differ considerably in density, although nominally the same.

The following are Stillwell's determinations;

40. —TABLE OF SPECIFIC GRAVITY OF OILS.—STILLWELL.

COËF. OF EXP. = .00063 FOR 1° C.
= .00035 FOR 1° F.

	15°C. 59°F.
Sperm, bleached, winter	.8813
" natural, winter	.8815
Elaine	.9011
Red, saponified	.9016
Palm	.9046
Tallow	.9137
Neatsfoot	.9142
Rape-seed, white, winter	.9144
Olive, light greenish yellow	.9144
Olive, dark green	.9145
Peanut	.9154
Olive, virgin, very light yellow	.9163
Rapeseed, dark yellow	.9168
Olive, virgin, dark clear yellow	.9169
Lard, winter	.9175
Sea elephant	.9199
Tanners' (cod)	.9205
Cotton-seed, raw	.9224
Cotton seed, refined, yellow	.9230
Salad (cotton-seed)	.9231
Labrador (cod)	.9237
Poppy	.9245
Seal, natural	.9246
Cocoanut	.9250
Whale, natural, winter	.9254
Whale, bleached, winter	.9258
Cod-liver, pure	.9270
Seal, racked	.9286
Cottonseed, white, winter	.9288
Straits (cod)	.9290
Menhaden, dark	.9292
Linseed, raw	.9299
Bank (cod)	.9320
Menhaden, light	.9325
Porgy	.9332
Linseed, boiled	.9411
Castor, pure cold-pressed	.9667
Rosin, third run	.9887

41. The mineral oils are usually lighter than those of animal or vegetable origin. Crude Pennsylvania petroleum has a composition*:

Carbon	84
Hydrogen	14
Oxygen	2
	100

The average density is about 45° B. and is composed of a considerable number of compounds which vaporize at temperatures varying from 32° to 700° Fahrenheit (0° to 370° Centigrade).

The following are the densities of these oils:

MINERAL OILS, 60° F, 15° C.

	S. G.	B.
Rhigoline	.6220	95
Benzine	.6510	85
Naptha	.7000	70
"	.7500	57
Illuminating oil	.8000	45
Lubricating oil (heaviest)	.8860	26
Paraffine wax	.8900	27

42. The following table gives degrees of Beaumé and the corresponding specific gravities in parallel columns, together with the weight of one gallon at each density*:

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* The Eames System of Furnace-working of Petroleum; by Prof. H. Wurtz; "Trans. Amer. Inst. Mining Engineers," 1875; "Eng. & Mining Journal," Aug., 1875; "Iron Age," Aug., 1875; "Am. Chem.," Sept., 1875; London "Iron," Sept., 1875.

† For most valuable tables in addition to those here given, see Prof. S. A. Latmore's Computation Tables, Rochester, 1872.

SPECIFIC GRAVITIES AND DENSITIES.

DEGREES.		LBS. IN ONE GAL.	DEGREES.		LBS. IN ONE GAL.
B.	S. G.		B.	S. G.	
10	1.0000.	8.33	44	.8045	6.70
11	.9929	8.27	45	.8000	6.65
12	.9859	8.21	46	.7954	6.63
13	.9790	8.16	47	.7909	6.59
14	.9722	8.10	48	.7865	6.55
15	.9655	8.00	49	.7821	6.52
16	.9589	7.99	50	.7777	6.48
17	.9523	7.93	51	.7734	6.45
18	.9459	7.88	52	.7692	6.41
19	.9395	7.83	53	.7650	
20	.9333	7.78	54	.7608	
21	.9271	7.72	55	.7567	
22	.9210	7.67	56	.7526	
23	.9150	7.62	57	.7486	
24	.9090	7.57	58	.7446	
25	.9032	7.53	59	.7407	
26	.8974	7.48	60	.7368	
27	.8917	7.43	61	.7329	
28	.8860	7.38	62	.7290	
29	.8805	7.34	63	.7253	
30	.8750	7.29	64	.7216	
31	.8695	7.24	65	.7179	
32	.8641	7.20	66	.7142	
33	.8588	7.15	67	.7106	
34	.8536	7.11	68	.7070	
35	.8484	7.07	69	.7035	
36	.8433	7.03	70	.7000	
37	.8383	6.98	75	.6829	
38	.8333	6.94	80	.6666	
39	.8284	6.90	85	.6511	
40	.8235	6.86	90	.6363	
41	.8187	6.82	95	.6222	
42	.8139	6.78	100	.6087	
43	.8092	6.74			

43. Rousseau has shown that the oils, with the exception of olive oil, which has nearly $\frac{1}{100}$

the conductivity of other oils, are good conductors of electricity, and has devised an instrument to detect adulterations of that oil which is called the diagometer. The test is made by measuring their conductivity. The instruments used are simply a galvanometer and a small voltaic battery, the current of which is passed through a small drop of the oil to be tested and its intensity is then measured by the galvanometer. A comparison with known oils gives the evidence sought.

44. THE EFFECT OF HEAT upon oils furnishes another means of determining their character and of detecting falsifications.

The temperature of distillation of petroleum products varies from 80° to 250° F. (27° to 120° C.), for the napthas, 250° to 600° F. (120° to 315° C.) for illuminating oils, or to 600° 800° F. (315° to 425° C.) for the heavy lubricating oils. The very best oils of the latter class have no bad odor, and only vaporize at 600° F. (315° C.) or higher. Their density is about 27 or 28 B. (0.890 Sp. Gr.) They are rarely used unmixed with lighter oils.

45. FIRE TEST. The temperature of decomposition of the mineral oils is a good gauge of their values. An oil should not generally be used which takes fire at so low a temperature as 250° F. Some of the best oils do not burn,

or even give off much vapor at a temperature of 300° or more. This "fire test" is usually made with a little piece of apparatus made especially for the purpose. This is shown in fig. 3. It

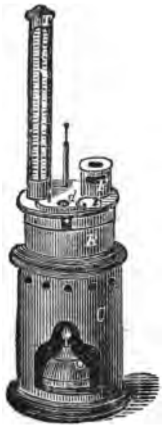

Fig. 3.

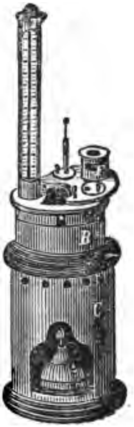

Fig. 4.

consists of a little tank, in which the oil to be tested is poured. This is placed in another large cup, *B*, and the space between is filled with water for ordinary tests. A lamp beneath supplies the heat, and a thermometer, *T*, set in the cup, with its bulb in the oil, shows the temperature.

As the oil becomes heated, the observer occasionally applies a lighted match or taper to the opening, *C*, of the cup. After a time a flash is seen when the match is applied, and the flame disappears as suddenly as it has appeared. This shows that vapor has been produced in sufficient quantity to mix with the air above the oil, and produce an explosive mixture. The temperature now observed is called the "flashing point." At some higher temperature, if the cap is moved to one side, as shown in figure 4, and a match is applied, the oil takes fire and burns. This is the so-called "burning point." It may be 20 degrees or more above the flashing point.

This is the Tagliabue apparatus.

Mr. Millspaugh, of Kent, Conn., has recently introduced a somewhat similar apparatus, which is represented in the accompanying illustration. It consists of a sheet metal chamber which receives a lamp below, and a glass vessel, *A*, above. The latter is formed with a contracted lower portion, so that the wider part above makes a shoulder, enabling the glass to be firmly set in the orifice over the lamp. The vessel is surmounted by a suitable cover, in which there is a filling aperture, *B*, and another opening. at which the test is made. To the cover is also attached a small thermometer, as shown.*

The rate of heating should be about 20° F in a quarter of an hour

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* Scientific American," March 18th, 1876.

The method of using the apparates is similar to that already described, and consists in filling the glass to the point, *C*, with the oil to be tested. The lamp is then lighted, and a taper is from time to time applied to the cover orifice,

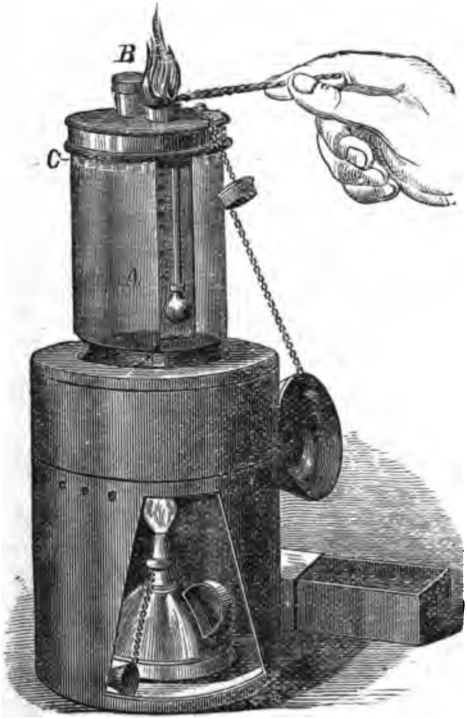

Fig. 5.

as represented in the engraving, until a flash takes place, when it remains only to note the temperature of the oil as indicated by the thermometer. The tapers are shown in the small box beside the apparatus, and are supplied with the latter.

When it is desired to determine the degree of heat at which the fluid actually takes fire and burns—the fire test—the appartaus may be used by removing the cover (leaving the thermometer in the fluid) and touching the surface of the oil with the taper.

Sufficient oil is held in the glass vessel for a satisfactory trial; and the process of heating is slow and gradual, approximating closely to the manner in which the oil is heated when it is used for domestic purposes. Illuminating oils are usually required to have a flashing point above 110° F. (43 C.), and lubricating oils should always flash above 250° F. (120° C.), and take fire at a considerable higher point. Satisfactory figures for the two classes of oils would be at least one-half higher, or, better still, twice as high.

The Bailey fire test apparatus is seen in the next sketch. The oil is heated in a small copper tank through which rises the flue within which is the flame of the lamp or gas-burner.

This vessel is filled only about three-fourths full of oil. The vapor formed rises at the centre, passing the bulb of a thermometer set at the top of the central vapor-flue, and issues laterally and is ignited at the jet.

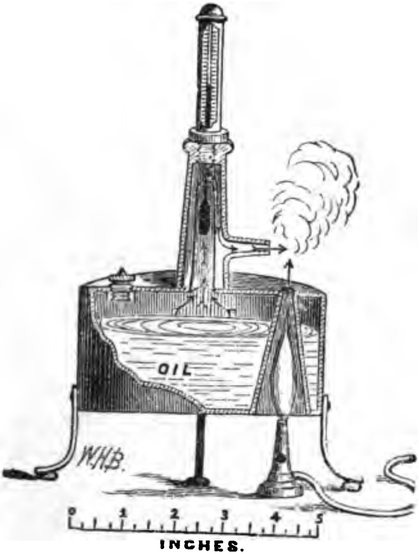

Fig. 6.

The animal and vegetable oils do not vaporize, but decompose at high temperature.

The following are results obtained with the first of the three kinds of apparatus described:

OILS.	TEMPERATURES—FAHR. AND CENT.					
	Flash.		Take Fire.		Burn.	
	F.	C.	F.	C.	F.	C.
West Va. Oil	245°	118°	290°	143°	300°	149°
Winter Sperm	425°	219°	485°	252°	500°	260°
Lard	475°	246°	525°	274°	525°	274°

The flashing and the burning points of the temperature of decomposition can thus be found, and liability to injury by heat determined, or safety in the presence of fire; and a determination of temperature of thickening or congelation will show whether it may be used for out-of-door applications in cold climates. The standard animal and vegetable oils and all mineral oils of good "body" and density only decompose or vaporize at a temperature exceeding that of the steam in ordinary steam engines, and the latter sometimes, and the former two usually, bear even steam at locomotive pressure. The good mineral oils do not congeal at any ordinarily low temperatures, the heavier oils freezing at 20° F. and the lighter remaining liquid at 0°. Summer sperm thickens at about 65° F., freezing at about 50°, winter sperm at about 50° and 35°; and lard oil begins to harden at 40°, solidifying at 25° F.

To determine the behavior of an oil at low temperatures, place 15 parts Glauber's salts in a glass vessel; insert a small bottle of the oil to be tested; add, above the salts, a mixture of 5 parts hydrochloric (muriatic) acid with an equal quantity of water, and watch the oil during the process of cooling which then commences, stirring the oil with a thermometer, which will indicate its temperature. Ice and water, or a mixture of ice and salt, will also be found useful cooling agents.

46. TESTS WITH ACID.—The addition of concentrated sulphuric acid to oils was found by Maumené and by Fehling to produce considerable heat, and they were able to distinguish them by measuring the resulting increase of temperature. The drying oils heat most and disengage sulphurous acid. The following are given by Chateau as their determinations:

OILS.	INCREASE OF TEMPERATURE.	
	Maumené.	Fehling.
Olive Oil	42°	37·7°
Poppy "	74·5°	37·7°
Colza "	58°	37·7°
Almond "	53·5°	40.3°
Rapeseed "	57°	55°
Linseed "	133°	74°
Sesame "	68°	74°
Castor "	47°	74°
Cod-liver "	103°	74°

Maumené added 10 c. c. of acid to 50 grs. of each oil. Fehling used but 15 grs. of oil. The acid had a density of 66° B. The results are thus not precisely comparable; but it seems evident that this method is either not at all accurate or was not well practiced by one or the other of these investigators.

Coleman describes* similar tests in which he added sulphuric acid to rape and to olive oil, and observed a rise of 100° and 68° F. respectively. The same experimenter saturated cotton waste with oil and raised its temperature to 150° or 200° in an air-bath, noting the time required to produce spontaneous ignition and combustion. Boiled linseed oil took fire in 1¼ hours; raw oil in 4 hours, while refined rape-seed oil required 9 hours of exposure. The addition of 20 per cent. mineral oil greatly retarded, and 50 per cent. entirely prevented, ignition.

47. IMPURITIES OF MINERAL OILS.—The admixture of a mineral oil with any other oil can be often readily detected by shaking the suspected oil in a bottle until bubbles of air are formed, when, holding the bottle up to the light, the mineral oil, if present, will produce a peculiar iridescence, which is an unmistakable evidence of the adulteration. The presence of "still-bottom" impurities is also a proof of the

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* "Trans. Phil. Soc. of Glasgow," 1873.

mixture of mineral oil. These consist of fine solid particles of the coating formed on the bottoms of the apparatus in which the fractional distillation of mineral oils takes place. They may be detected, sometimes, by the abnormally low temperature at which the oil vaporizes in contact with them, or by dropping the suspected oil on white blotting paper, which will absorb the oil, leaving the black specks of impurity visible.

48. OLEOGRAPHY.—Still another, and a very beautiful, although rarely practiced, method of identifying oils of various kinds, is that introduced many years ago by Professor Tomlinson, who first applied it to the exhibition of the characteristic differences between the essential oils, and termed the peculiar and beautiful forms produced "cohesion figures."

It was again brought forward by Dr. Moffat* and by him applied to the identification of the commercial oils and the detection of adulteration. The process, as perfected by Dr. Moffat, is now familiar under the name of "oleograph tests." We proceed thus: Wash out a large basin very carefully with water and alkali until it is chemically free from foreign matter, and fill with perfectly clean water. When the surface has become quiet, drop upon it a single drop of the oil to be examined. The oil at once spreads rapidly over the surface of the water in an exceedingly thin film. Presently the film commences breaking up, small openings appearing through it, which gradually enlarge and group themselves into peculiar lace-like patterns. These lace patterns continue changing, and finally the surface of the water is covered with detached and very minute particles of oil. Each oil, under the same set of standard conditions, exhibits a peculiar behavior that is always characteristic of the oil and which can therefore be made of use in identifying it. Each oil spreads at a certain rate, and each, *at a given instant* during the process of change, forms a peculiar and characteristic lace. A comparison of the pattern produced in testing the several oils and of the times of observation enables the experimenter to judge, by comparison with his standards, whether the oils tested in this way are pure or adulterated.

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* "Chemical News," vol. XVIII p. 299.

In doing this work it is important to be able to secure copies of the patterns thus obtained. This is done by a very simple and neat process: Provide another basin containing water rather strongly colored with ink, and a quantity of white blotting-paper cut into pieces of such size and shape that they can be laid upon the surface of the water in the testing basin.

The observer stands, watch in hand, noting the changes progressing in the film of oil. At the proper moment—a half-minute, a minute or two minutes, whichever may have been found a proper standard time, measured from the falling of the drop—he carefully and quickly lays a piece of his blotting-paper down on the film; then as quickly and carefully transfers it to the surface of the ink solution, At the first contact every point in the surface transfers to the pages a particle of water or a particle of oil, and the lace-pattern is now present on the paper in oil and water. On placing the blotting paper on the colored water, all parts of the surface unprotected by oil are stained, while the rest remains uncolored, and the beautiful lace-pattern appears in black and white in permanent and preservable form. The sheet is next marked with the name of the oil, the date of the test and the time allowed for the formation of the pattern. It still remains to be determined by further experiment how far the method may be made practically valuable and reliable.

The special precautions to be observed in practicing this method of test are to secure an absolutely perfect cleanliness of the vessels used, and to note with care that oleographic figure which is most thoroughly characteristic of the oil under test; this is found to occur at one instant during the uninterrupted process of change of each film of oil, and the patterns which precede and which succeed it are comparatively valueless.

The vessels should be cleaned perfectly with a solution of caustic potash or soda after each experiment. The oil should be let fall in a single drop upon the exact centre of the surface of water from a glass rod, and in such a manner that no disturbance is produced. These rods, when not in use, should be kept in a solution of caustic potash, and, when used, should be drawn through clear water and wiped upon a clean cloth before dipping them in the oil.

Occasionally, when the vessels have been some time in use, it will be necessary to wash them and the rods in strong sulphuric acid;* they should then be thoroughly rinsed.

The symmetry of the figures produced, as well as their characteristic forms, is injured or destroyed by adulteration, and sometimes by physical changes occurring under exposure to air, and with age. Solid carbolic and camphor treated in this manner yield curiously active spots and figures.

The time at which the distinctive figure is formed is an absolutely essential element, as already stated, and it is therefore always advisable to first prepare a set of standards by obtaining oils of known purity and taking off oleographs, at intervals of ten seconds or of one minute, according to the rapidity of change, and this series should be preserved for comparison with the results of test of suspected oils.

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* "Chemical News," vol. XIV., p. 46.

Dr. Moffat thus made up an Oleograph Album of standards. In the series for each oil, the most thoroughly characteristic figure should be given some distinguishing mark, or otherwise identified. The oleographs may be given any desired color by using, instead of ink, a solution of the color desired. They may be readily photographed, or they may be transferred to stone.

49. GUMMING AND DRYING.—Still another special physical test determines the degree to which the oil is liable to injury by gumming. The usual method is that of Nasmyth, who uses this very simple mode of determining the viscosity and the rate of "gumming" of oils. He places a drop at the top of an inclined plane, and notes the time required for it to run down the plane. Of oils which do not gum, the least viscous reach the bottom first. Drying and gumming oils are retarded in proportion to the rate of drying or of gumming. He uses a plate of iron, 4 inches wide by 6 feet long, on the upper surface of which six equal-sized grooves are

planed. This plate is placed in an inclined position, say one inch in six feet. The mode of testing is as follows: Suppose we have six varieties of oil to test, and we are desirous of knowing which of them will, for the longest time, retain its fluidity when in contact with iron and exposed to the action of air; all we have to do is to pour out *simultaneously*, at the upper end of each inclined groove, an equal quantity of each of the oils under examination. This is very conveniently and correctly done by means of a row of small brass tubes. The six oils then make a fair start on their race down hill; some get ahead the first day, and some keep ahead the second and third day, but on the fourth or fifth day the truth begins to come out; the bad oils, whatever good progress they may have made at the outset, soon come to a standstill by their gradual coagulation, while the good oil holds on its course; and at the end of eight or ten days there is no doubt left as to which is the best; it speaks for itself, having distanced its competitors by a long way. Linseed oil, which makes capital progress *the first day*, is set fast after having traveled 18 inches, while second-class sperm beats first-class sperm by 14 inches in nine days, having traversed in that time 5 feet 8 inches down the hill. The following table shows the state of the oil race after a nine days' run:

RESULT OF OIL TEST.*

Description of Oil.	First Day....	Second Day..	Third Day...	Fourth Day..	Fifth Day....	Sixth Day...	Seventh Day..	Eighth Day...	Ninth Day...
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft in.	ft. in.	ft. in.
Best sperm oil..	2.8½	4.2	4.5¾	4.6	4.6	4.6	4.6⅓	stat...	......
Common sperm oil..........	1.7	3.9	4.6¾	4.11	5.1½	5.4	5.6¾	5.7⅜	5.8
Galipoli oil....	0.10¼	1.2¼	1.6	1.6½	1.7⅝	1.8¾	1.9	1.9¼	1.9⅛
Lard oil.......	0.10¼	0.0½	0.10¾	0.10¾	0.11¾	..stat.	......	......	......
Rape oil......	1.2½	1.6¼	1.7	1.7⅓	1.7¼	1.7¼	1.7¼	1.7¾	..stat.
Linseed oil....	1.5½	1.6	1.6¾	1.6¼	1.6½	1.6¼	1.6¼	..stat	......

This process is in use in the Mechanical Laboratory of the Stevens Institute of Technology. The surface is of glass, however, instead of metal.

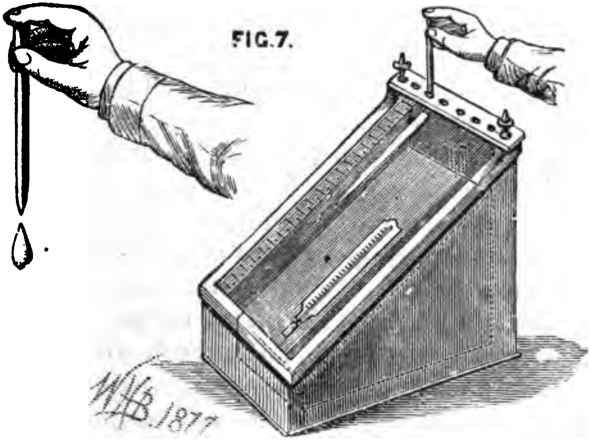

FIG. 7.

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* Appleton's "Dictionary of Mechanics," Vol. II.

A modified apparatus is described by Mr. W. H. Bailey, and is illustrated in this sketch. It consists of a piece of plate-glass set with considerable inclination, and heated, by means of a vessel of boiling water, to about 200° F. (93° C.), and held at a uniform temperature, as indicated by the thermometer attached. A drop of oil placed at the top will flow down a few inches, as in Napier's test, and, if permitted to remain upon the glass some days, will give evidence of any tendency to gum. A scale on the side of the box affords a convenient means of measuring the track of the flowing drop. Watch oil is tested in Switzerland somewhat similarly. If the oil is found to become decidedly resinous after two or three days exposure to heat, it is condemned.

A very simple and commonly used test of the fluidity of the oil consists in dipping into it a piece of blotting paper, and then watching the falling drops as it is held above the surface of the oil. Should the oil fall in distinct, symmetrical, pearl-like drops, it is an evidence of fluidity; a tendency to spread is the indication of viscidity. Retaining the oil on the paper, at a temperature of 200° F., for some hours, or at ordinary temperature for some days, will enable the observer to judge of the rate of gumming also.

Still another method is that in which the oils, at a standard temperature, are allowed to flow from a vessel, kept filled to a uniform depth, through an orifice of standard size. The amount discharged will be the greater the more fluid the oil; or the vessel may be of any convenient capacity, or may have any standard volume of oil put into it, and the time required to empty it may be observed. Coleman thus found that while sperm flowed through a funnel in 5 minutes, a mineral oil required but 3 minutes, and lard took 7 minutes; a mixture of mineral oil and lard, in equal parts, ran through at the same rate as sperm; rape required 8 minutes, seal oil 6^{1} and neatsfoot 8½ minutes.

50. Chemical Methods of Test have been proposed in great variety. In general, the chemist first compares the density of the oil to be examined with that of the standard pure oil of the same denomination as given in the printed tables.

Animal and vegetable oils are distinguished by the fact that chlorine turns animal oils brown and vegetable oils white.* Some special tests are quite reliable for certain adulterations, and chemists have devoted much time to their discovery and to perfecting methods. One of the best treatises on this subject is that of Chateau, already referred to, and from it I have translated some of the most important paragraphs, and have made abstracts of others. I will present them at some length.

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* "Moniteur des Produits Chemique," 1875.

51. GENERAL METHOD OF ANALYSIS OF OILS.*

When, without any previous knowledge of the nature of any substance, it is proposed to discover all its constituent parts and to furnish a proof that, besides the elements exhibited by analysis, it does not contain others, it is necessary to proceed with a method, and to follow strictly a systematic plan.

Methods of analysis may be numerous and of various kinds, but they are founded upon the same principles and all present the same character.

In fact, in *all* methods of analysis, certain reactions are made use of, which enable us to divide all bodies, or all those under consideration, into classes that are perfectly defined.

Such characteristics are always made use of that each of these sections shall comprise, as nearly as possible, equal numbers of bodies which exhibit in the same degree the reactions which have served to establish the group.

By another set of characteristics, new divisions and sub-divisions are established in each of these classes.

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* Extract from a memoir "On the Falsification of Fatty Bodies in General, and of the Oils in Particular," presented to the "Société Industrielle de Mulhouse" in Feb. 1861, and which was voted the silver medal.

Proceeding in this way, a certain number of substances are eliminated, with which we need no longer occupy ourselves, and, after some tests, usually but few in number, we acquire the knowledge that the elements of the composition submitted to analysis belong to such or such section or class or to one of the divisions or subdivisions.

It is only after having arrived at this result that we seek to determine, by a special method, the body considered, by making use of specific characteristics and particular reactions.*

52. It is a similar method that Chateau follows in the analysis of the fatty bodies generally and the oils in particular.

He proposed, by general reactions, to form a first classification which facilitates the determination of the nature of the oil, and consequently allows its purity to be judged.

These general reactions are :

1st. The use of bi-sulphide of calcium, giving a soap which remains colored or loses its color.

2d. The colors given with the sirupy chloride of zinc.

3d. The colors produced by ordinary sulphuric acid.

4. The colors produced by forming bi-chloride of tin.

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* Precis d'Analyse Chemique Qualitative, M. M. Gerhardt et Chancel.

5. The colors given, both cold and warm, with the sirupy phosphoric acid.

6. The colors given by the pernitrate of mercury employed alone or together with sulphuric acid.

These general reactions are rendered complete by the use of several other re-agents, potassa, ammonia, nitric-acid, etc., the use of which will be stated in the monography of the fats.

Finally, the nature of the oil will be ascertained with certainty by testing for special characteristics and particular reactions as indicated in each monographing.

The tests may be made in a large watch glass placed on a white paper, on a glass plate, also on white paper, or in a small white porcelain capsule. In practice the watch glass has been preferred.

53. Preparation and Use of the Re-agents.

Bi-sulphide of Calcium.—This is easily prepared by boiling a mixture of flowers of sulphur with chalk and water. After boiling a half-hour, it is filtered. That which has been prepared several days is to be preferred.

Chloride of Zinc (sirupy.)—This re-agent is prepared by saturating pure hydro-chloric acid with oxide of zinc and evaporating to dryness, A sirupy aqueous solution is made of the product.

Sulphuric Acid (*commercial and colorless.*)—This acid is used in the proportion of 3 or 4 drops to 10 or 15 drops of oil.

Bi-chloride of Tin (*fuming.*)—This re-agent is obtained from dealers in chemicals. It is also called the "*fuming liquor of Libavius.*"

Phosphoric Acid (*sirupy.*)—A strongly concentrated solution resulting from the action of nitric acid upon phosphorus, or else a sirupy solution of phosphoric acid prepared in advance, or, better still, bought of the druggist.

Pernitrate of Mercury.—This is prepared by dissolving mercury in an excess of pure nitric acid. The use of this re-agent is two-fold: 1st, in the observations of color produced by the salt alone; 2d, in observations of the colors produced by sulphuric acid when poured over the oily mass after the action of the salt of mercury.

Potassa.—Concentrated solution of caustic potassa. The author has used alcoholic potassa.

Ammonia.—That of commerce—colorless.

Nitric Acid (*pure.*)—Commercial.

All those re-agents are employed by pouring a few drops (4 or 5) on the oil, which is placed in a watch glass, covering a surface about equal to that of a franc—French.

With the concrete oils, the fats, tallows and waxes, four or five drops of the re-agent are used with a piece of the fat of the size of a pea.

54. The tables following give a resumè of the reactions of the oils when they are subjected under similar conditions to the general re-agents already indicated.

To facilitate and guide investigation the oils are divided into the drying and the non-drying oils and animal oils.

BISULPHIDE CALCIUM. Gives Golden Yellow Color. Permanent.			BISULPHIDE CALCIUM. Golden Yellow Soap, losing Color Quickly on Agitation, and becoming Canary Yellow or Pale Yellow.		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Linseed (English).	Olive.	Neatsfoot.	White Poppy (India).	Olive (ord'ry salad).	Neatsfoot (Buenos Ayres).
Do. Northern Europe.	Sweet Almond.	Tallow Oil (or Oleic Acid) (with sulphuretted hydrogen gives a decided dark gray color).	Hemp Seed.	Olive (huile d'enfer).	Neatsfoot (Paris).
Do. (Bayonne).	Colza.	Sperm.	Castor.	Peanut.	Horse Foot.
Do. (India).	Rape Seed.			Beech.	Seal.
Poppy (French).	Sesame.			Olive (refuse) (dense yellow soap, becoming grass green, then greenish white).	Fish.
Nut (Walnut).	Camline.				Whale.
	Cotton Seed.				Cod Liver (Dunkirk).

NOTE.—The re-agent is added, and with a glass rod stirred into the oil. It seldom requires more than a dozen strokes to cause the golden yellow color to change, becoming faint yellow.

CHLORIDE ZINC.

Either white mass, slightly yellow, or n color.			Yellow. (Y.) Orange Yellow. (O.Y.) Flesh Rose. (F. R.) Dark Brown. (D. B.)			Greenish Yellow. (G. Y.) Green. (G.) Bluish Green. (B. G.)		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying..*	*Fixed.*	*Animal.*
Poppy (French).	Sesame.	Neatsfoot (Paris).	Linseed (English). [Y.]	Rape Seed.	Horse Foot (yellow hot).	Linseed (India).	Colza.	Cod Liver (hot)).
	Sweet Almonds (hot pressed).			Peanut.			Camlin.	
Do. (White India).		Do. Buenos Ayres.	Castor (rose yellowish).	Beech (F. R.)	Whale (Y. B. hot).	Linseed (Bayonne).	Sweet Almonds (cold).	Ray Liver (hot).
Nut.		Sheep Foot.		Cotton (D.B.)	Tallow oil.	Linseed (N. Europe).	Olive (refined). (greenish.)	
		Horse Foot (cold pressed)			Fish.			
					Seal (R. B.)			
		Sperm,					Olive (ordinary).	
					Rayliver (Y. R. cold).			
		Whale (no color).					Olive (huile d'enfer).	
		Cod Liver (cold pressed					Olive(refuse).	
							(remains green).	

SULPHURIC ACID.

Dragon's Blood, (D. B.) Dark Reddish Brown, (R. B.) Brownish Red. (B. R.)			Yellow, (Y.) Dark Yellow, (D. Y.) Reddish Yellow (R. Y.) Orange Yellow. (O. Y.)			Either green veins or green coloration, or becomes greenish by agitation.		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Linseed (N. Europe). Linseed (Bayonne). Linseed (India). (with agita'n). Nut (with agitation).	Peanut. Beech (agitated). Cotton.	Neatsfoot (Buenos Ayres). (with agitation). Horse Foot (agitation.) Tallow. Fish (brownish black). Seal (D. B. dark). Sperm (B R.). Whale (B.R.) Cod Liver. (violet red—crimson, agit., violet, then D. B.) Ray Liver (do.)	Linseed (India). (O. Y., without agitation). Poppy (French). (bright Y. and O. Y.) White Poppy (India). (light Y., gold Y. and O. Y.) Castor. (bright Yellow, then R. Y.)	Olive (refined). Y. (without agitation) Do. (ordinary) (Y. without agitation, R. Y., with agitation.) Do. (huile d'enfer). Y. then R. Y. Sesame Beech, D. Y. (no agitation.) Sweet Almond. (Y. no agitation.) Camline. R. Y.	Neatsfoot (Paris). (Y. then O. Y.) Sheep Foot. (Y. and R. Y.)	Hempseed. Linseed (English). (with agitation.)	Colza. Camline. Olive (refined). Sesame (agitated). Rape Seed. Sweet Almond. (greenish Y., agitated.) Camline (green veins).	

FUMING BICHLORIDE OF TIN.

The Coloration Takes Place Instantaneously.

Yellow, Faint Yellow, (F.Y,) Golden Yellow, no color.			Brownish Red, Distinct Brown, (D. B.) Reddish Yellow, (R. Y.) Brownish Yellow. (B. Y.			Green, Greenish-Bluish Green, Greenish Blue.		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Poppy (French). Castor.	Olive (refined) do. (ordinary) Sesame (F. Y.) Sweet Almonds (no color).	Neatsfoot (Paris). Sheep Foot (F. Y.)	Linseed (English). (B. Y.) Do. (N. Europe). Do. (Bayonne). Do. (India). White Poppy (India). (R. Y.) Nut (R. Y.)	Olive (huile d'enfer). (R. Y.) Peanut (distinct B). Camline. Beech (R. Y.) Cotton Seed O. Y. (?)	Neatsfoot (Buenos Ayres). R. Y. Horse Foot, (R. Y.) Tallow, (R. Y.) Whale, (O. Y.) Sperm (purplish R. B.) Seal. Fish (deep R. B.)	Linseed (English), green veins. Do. (North Europe), (bluish G.) Do. (Bayonne), (bluish G.) Do. (India), (bluish G.) Hemp Seed.	Rape Seed. Colza.	Cod Liver, violet blue, reddish-violet, violet of pansy, scarlet, Dragon's Blood. Ray, same.

FUMING BICHLORIDE OF TIN.

Color of the Thickened or Solidified Mass.

Yellow, Faint Yellow, (F. Y.) Bright Bright Yellow (B. Y.) Straw Yellow.			Brown, Distinct Brownish Red, (D.B.R.) Orange Yellow,)O. Y.) Reddish Yellow. (R. Y.)			Green, Greenish, Dirty Green, Dark Green.		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Poppy (French).	Olive (refined).	Sheep Foot (Faint, rosy Y).	Linseed (English). (D. B. R.)	Olive (Ordinary). (O. Y.)	Neatsfoot (Paris) (O. Y.)	Hemp Seed. (Dark green)	Olive ("*lampante*"). (dirty green)	Ray (Y.G. reddish.)
White do. (India).	B. Y.		Do. (North Europe). brownish grey.	Do. (huile d'enfer). (R. Y.)	Neatsfoot (Buenos Ayres). (O. Y.)		Rape Seed (dirty green)	
Castor (faint).	Sesame.		Do. (India). (R.Y.)	Colza.	Horsefoot (O. Y.)			
	Sweet Almond (Canary Y).			Peanut. (B. R.)	Tallow (does not solidify). (R. B.)			
	Camline (Faint Y).			Beach (distinct R.Y.)	Whale (clear mahogany).			
				Cotton(Y.B.)	Sperm (O. Y.)			

PHOSPHORIC ACID.

Colors Exhibited when Cold.

White, No Color, Discoloration, Grey, Slightly Yellowish.			Yellow, Straw, Golden Yellow, Orange Yellow. (O. Y.)			Green, Greenish, Bluish, Dark Green.		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Poppy (French). (white).	Sweet Almond (discolored.)	Neatsfoot (Paris).	Linseed (N. Europe).	Sesame. (S. Y.) & (O. Y.)	Whale (S. Y.) then (O. Y.)	Linseed (English).	Olive (refined).	
White Poppy. (India). (white.)	Rapeseed	Sheep Foot.	Linseed (Bayonne).	Peanut (S. Y.)	Neatsfoot (Buenos Ayres).	Do. (North Europe).	Do. (ordinary).	
Nut (white.)	Do.		Linseed (India.) (straw yellow.)	Cotton (gold. Y.)	Horse Foot (O. Y.)	Do. (Bayonne).	Do. (huile d'enfer.	
Castor (white)	Camline				Tallow (S. Y.)	Hemp Seed (D. G.)	Colza	
	Do.				Sperm (S. Y.)		Rape Seed	
					Seal (distinct br. red.)		Camline.	
					Fish (R. Y.)			
					Cod (R. Y.)			
					Ray (gold Y.)			

PHOSPHORIC ACID.

Colors Exhibited when Hot.

No Coloration.			Yellow, Gold Yellow, Orange Yellow, Reddish Yellow, (R. Y.) Bright Yellow, (B. Y)			Froth —White or Gray, (G.) Black or Blackish. (B.)		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Poppy (French).	Olive (superfine). Do. "*lampante*").	Sheep Foot.	Linseed (N. Europe), (B. Y.) Do. (Bayonne), (B. Y.) White Poppy (India), (B. Y.) Hempseed, (R. Y.) Nut, (B. Y.) Castor, do.	Olive (ordinary). Do. (huile d'enfer), (R. Y.) Sweet Almond, (faint Y.) Colza, do. Rape Seed, Do. Peanut, (gold Y) Camline, (faint Y.) Sesame, do. Beech, do. Cotton, do.	Neatsfoot (Paris), (B. Y.) Do. (Buenos Ayres), (gold Y.) Horse Foot, (gold Y.) Tallow, (gold Y.) Sperm (B.Y.)	Sesame, (greenish.) Linseed (N. Europe), (Blackish.) Do. (Bayonne), (Gray.) Do. (India), (Blackish.) White Poppy, (gray.) Hemp Seed, (green or greenish.) Castor, (black)	Olive (ordinary), (G.) Do. (huile d'enfer). Colza, (B.) Rape Seed,(B.) Peanut, (G.) Camline, (G.) Beech, (B.) Cotton, (gray.)	Neatsfoot, (blackish.) Seal. Fish. Whale, (greenish B.) (Sperm, G.) Cod, (G,) (dirty green.) Ray, (do.)
Browns—Reddish Brown, Blackish Brown.								
		Seal. Fish. Whale. Cod. Ray.						

PERNITRATE OF MERCURY.

Colors Given by the Salt Alone.

White or Gray Emulsion, or No Coloration.			Yellow, Faint Yellow, Gold Yellow, (G. Y.) Canary Yellow, Orange Yellow, (O. Y.) Straw Yellow. (S. Y.)			Greens—Greenish, Sea Green, (S. G.) Bluish Green.		
Dryiug.	*Fixcd.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Poppy (French),	Sweet Almond, (grayish white.)	Neatsfoot, (Paris).	Linseed (N. Europe), (S. Y.)	Olive (refuse), (G. Y.)	Neatsfoot, (R.Y.)	Linseed (English).	Olive (superfine), (greenish Y.)	
White, (slightly yellowish.)	Sesame, (white)	Sheep Foot, (W.)	Linseed (Bayonne), (S. Y.)	Rape Seed, (S. Y.)	Horse Foot, (O. Y.)	Hemp Seed, (greenish after agitation.)	Olive (ordinary), (greenish Y.)	
White Poppy, (Do.)	Beech, (no coloration.)	Tallow, no) color.)	Linseed (India), (faint Y., with veins of dark Y.)	Peanut, (faint Y.)	Whale, (faint Y.)		Olive ("*lampante*"), (S. G.) and (Greenish Y.)	
(Nut, no coloration.)		Sperm, (no color.	Linseed (English), (faint Y.)	Camline, (S. Y.)	Seal, (reddish Y.)		Colza.	
Castor, (white.)				Sesame, (O. Y.)	Fish, (G.Y.)		Rape Seed, (S. G.)	
				Cotton, (faint Y.)	Cod, (S. Y.)		Camline. (faint G.)	
					Ray, (faint Y.)			

PERNITRATE OF MERCURY.

Colors Given by the Salt Alone.

White or Gray Emulsion, or No Coloration.			Yellow, Faint Yellow, Gold Yellow, (G. Y.) Canary Yellow, Orange Yellow, (O. Y.) Straw Yellow. (S. Y.)			Greens—Greenish, Sea Green, (S. G.) Bluish Green.		
Drying.	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*	*Drying.*	*Fixed.*	*Animal.*
Poppy (French),	Sweet Almond, (grayish white.)	Neatsfoot, (Paris).	Linseed (N. Europe), (S. Y.)	Olive (refuse), (G. Y.)	Neatsfoot, (R.Y.)	Linseed (English).	Olive (superfine), (greenish Y.)	
White, (slightly yellowish.)	Sesame, (white)	Sheep Foot, (W.)	Linseed (Bayonne), (S. Y.)	Rape Seed, (S. Y.)	Horse Foot, (O. Y.)	Hemp Seed, (greenish after agitation.)	Olive (ordinary), (greenish Y.)	
White Poppy, (Do.)	Beech, (no coloration.)	Tallow, no) color.)	Linseed (India), (faint Y,. with veins of dark Y.)	Peanut, (faint Y.)	Whale, (faint Y.)		Olive ("*lampante*"), (S. G.) and (Greenish Y.)	
(Nut, no coloration.)		Sperm, (no color.	Linseed (English), (faint Y.)	Camline, (S. Y.)	Seal, (reddish Y.)		Colza.	
Castor, (white.)				Sesame, (O. Y.)	Fish, (G.Y.)		Rape Seed, (S. G.)	
				Cotton, (faint Y.)	Cod, (S. Y.)		Camline. (faint G.)	
					Ray, (faint Y.)			

55. METHOD OF USING THE PRECEDING TABLES OF REACTIONS.—Before making use of the tables just given, it is best to notice the indications furnished by the employment of organoleptic methods; in fact, the odor, taste, color and consistence are characteristics that assist greatly in determining the method of adulteration.

Several cases may be presented in the analysis of oils.

1st. Having a commercial oil the name of which is unknown (without label or label effaced, for example), to ascertain what it is.

2d. Knowing to what class an oil belongs, but not knowing its name, to ascertain it. For example, knowing of an oil that it is a drying, fixed or animal oil.

3d. The name of an oil being certainly known, to ascertain whether it is pure or not.

These are three questions that the chemist, the purifier, or even the consumer may at any time be called upon to solve—particularly the last.

FIRST CASE.—*Knowing nothing of the oil, to Ascertain its Name.*

First try the bi-sulphide calcium as directed in the instructions for preparing re-agents.

Suppose, for example, the oil gives a golden yellow emulsion which retains its color. The oil tested may be linseed, nut, olive (superfine or "*lampante*"), sweet almond, colza, rapeseed, sesame, camline, cotton, sheepfoot, tallow or sperm. If in the reaction it does not produce effervescence and evolution of sulphuretted hydrogen, it cannot be tallow oil. That is eliminated.

Try next a current of chlorine for a quarter of an hour. If it produces no black coloration it is not sperm oil.

Try chloride of zinc. This re-agent gives a green, greenish, bluish green coloration; the table gives the linseeds of India, Bayonne and North Europe, colza, camline, sweet almond, refined olive, and the other grades of olive, cod and ray oils.

The oil tested cannot be the lower grades of olive oil, cod liver or ray liver. Bisulphide of calcium would have indicated them; on the other hand, it is not rapeseed, sesame, cotton, English linseed or sheepfoot, as the chloride of zinc would have detected them.

We are then limited to the linseeds of India, North Europe and Bayonne, colza, camline, sweet almond and the higher qualities of olive oil.

Try sulphuric acid. Suppose it gives, for example, a dark coloration of the tints reddish brown and "dragon's blood." Consulting the tables, it is seen that such effect indicates the linseed oil of different countries, and a series of fixed and animal oils which had been eliminated by the preceding tests.

The oil is, therefore, linseed oil, and it only remains to determine its origin.

The special reactions will be given in its monography.

Thus, without using the remaining tables, the name of the oil supposed to be offered for test is determined. By trying the reactions given by the other re-agents indicated, the nature of the oil can be still more precisely ascertained.

It is evident that another order of operations might have been followed, but it is indispensable to commence with the bisulphate of calcium. This re-agent divides the oils into two great groups; and to proceed from the use of simple to that of complicated tests.

SECOND CASE.—*Having given, for example, a Fixed Oil, to Ascertain its Name.*

Try bisulphide calcium. This re-agent may give, for example, a golden yellow emulsion, which retains its color.

They can be neither olive of low quality, peanut nor beech. It is useless to try chlorine here.

Pass on to chloride zinc. We may obtain, for example, a greenish bluish green; the oil cannot be a poor quality of olive oil, or sesame, or rapeseed, or cotton. There remain colza, illuminating olive or superfine, camline, sweet almond.

Test with sulphuric acid This re-agent gives, say, a reddish yellow color. This eliminates colza and illuminating olive oils, leaving camline, sweet almond and superfine olive.

Apply the fuming bichloride of tin. Perhaps a light brownish red may appear instantaneously, and with it a thick mass of faint or straw yellow color.

The first reaction eliminates sweet almond and best olive; the second confirms the first.

The oil must then be camline.

The special reactions given in the monography of this oil will clearly identify it.

The most unfavorable example has been selected to illustrate fully the use of the re-agents.

Had a soap been obtained which did not retain its color, it would have limited the further investigation to only four oils.

In such cases the labor is vastly reduced.

A similar process would determine the name of any animal oil.

The bisulphide calcium effects a primary division—three oils on one side and eight on the other. If the characteristics developed indicate one of the eight, the use of chloride will eliminate the fish oils, leaving it to be decided whether it is neats-foot or horse-foot oil.

THIRD CASE.—*To ascertain the Purity of any oil indicated.*

Here the investigation is limited.

As an oil is only adulterated with oils less costly, it is, usually, not difficult to decide upon a limited range of possible adulteration.

It is also evident that an oil can only be adulterated with a similar oil of inferior quality or one possessing very similar properties. Thus an edible oil could not be adulterated with an oil of strong odor, as olive with fish, etc.

It is true that a difference of price does not invariably limit adulteration, as the price varies in different seasons, and sometimes, even, from day to day. Thus colza is now quite costly, while linseed is cheap. The adulteration of colza with linseed is, therefore, quite probable—it is practiced to a great extent—but a season before, the contrary was the fact.

Suppose the purity of edible poppy oil is to be tested?

After having tried and noted the organoleptic indications, test with the bisulphide calcium. Suppose a soap obtained which retains its color? All the oils giving a soap which loses color are thus eliminated.

Without further test, an examination of the tables will show that the three animal oils, sheep-foot, oleic acid and sperm are also easily eliminated, these oils having characteristic odor and taste. The linseed oils also have odor and are not edible. The adulteration could not be with superfine olive oil, for it is too costly. Illuminating olive oil has a characteristic taste and odor, which places that on one side. Cotton seed oil, by its color and taste, and the oil of sweet almonds, by its price, are out of the question. There remains nut, colza, rapeseed, sesame, camline and poppy.

Try the chloride of zinc. Suppose a white or slightly yellowish mass be obtained? This reaction eliminates colza, rapeseed and camline, leaving nut, sesame and poppy.

Next use sulphuric acid, which may give a reddish yellow color. As the nut oil does *not* give this reaction, there remains sesame and poppy.

Trying the fuming bichloride of tin, it gives a *faint* yellow coloration and a *straw* yellow solidified mass. We still find these reactions to indicate sesame and poppy oils.

It then becomes certain that the poppy oil is adulterated with sesame.

Try then phosphoric acid. This gives, perhaps, a faint yellow—orange yellow. The detection is confirmed, since poppy oil should give a white emulsion. Lastly, turn to the monography and try Behrens' re-agent, which will determine unerringly the presence of the oil of sesame.

A difficult example has again been selected—one in which an oil has been adulterated with another having nearly the same characteristics, and giving very nearly the same reactions.

Another example might have been selected, with which the investigation would have been simpler and the result quite as certain.

This method will apply quite as well to the concrete oils, the greases and tallows.

Among the most common mixtures are the adulteration of sperm with blackfish or with whale oil; the mixture of cotton seed with otherwise good lard; the introduction of peanut (ground nut—earth nut) oil with olive, and the addition of an alkali with water or of plaster to tallow. Probably the greater proportion of the lubricating oils now in use are mixtures, and the most usual is an acknowledged mixture of mineral with animal oils.

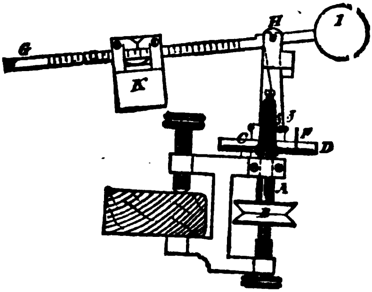
56. MACHINES FOR TESTING LUBRICANTS.—The most important of all the tests to be applied to determine the precise value of a lubricating material, and that which most completely and satisfactorily reveals that value, is applied by using some form of apparatus or machine specially constructed for the purpose.

In order to determine precisely what oils are adapted to any special purpose, or to ascertain for what uses any oil is best fitted, it is always necessary to make an examination of the lubricant working under the specified conditions. That is to say: the oil should be put upon a journal of the character of that on which it is proposed to use it, and, subjecting it to the maximum pressure proposed, running it at the maximum speed that the journal is ever expected to attain, its behavior will then show conclusively its adaptability to such an application. While running, it is necessary to be able to measure the friction produced and to determine its coefficient, which, as we have seen, is its measure, and to be able to note its durability and the rise in temperature of the bearing. These qualities being determined and recorded, all is known of the oil that is needed to determine its lubricating power.

As I have already stated, lubricants are tested to determine their value by placing them as nearly as possible under the conditions of actual work in machines designated for this purpose. A considerable number have been invented, although but two or three are in use.

One of the oldest is shown by figs. 8 and 9 of McNaught. It consists of two disks. The upper one is loose : the lower one is turned by a pully on its spindle. The oil is interposed between the disks, and the friction causes a tendency on the part of the loose disk to turn with the other. This tendency is resisted by a pin on its upper side coming in contact with the short arm of a bell-crank lever, the long horizontal arm of which carries a weight, which can be adjusted to measure the friction.

Fig. 8.



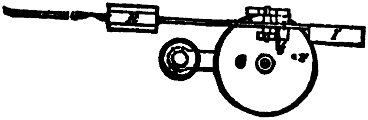


Fig. 9.

Fig. 8 is a side elevation, with the disks *C* and *D* shown in section, and fig. 9 is a plan. It consists of a disk, *D*, attached to a shaft, *A*, which is driven by a pulley, *B*. On top of *D* is another disk, *C*, which can turn on the shaft or spindle *A*. The oil to be tested is placed between these two disks. As the lower one turns, the friction between them carries the upper one with it, but its motion is restrained by a pin, *F*, which comes in contact with another pin, *f*, in the end of the arm of a T-lever, *CHIF*, which is pivoted at *H*. A movable weight, *K*, slides on the arm *GH*, on which is a scale to note its position. A counterweight, *I*, is attached to the opposite end of the lever, so as to afford the means of a more delicate adjustment. It is evident that the resistance due to the friction between the two disks

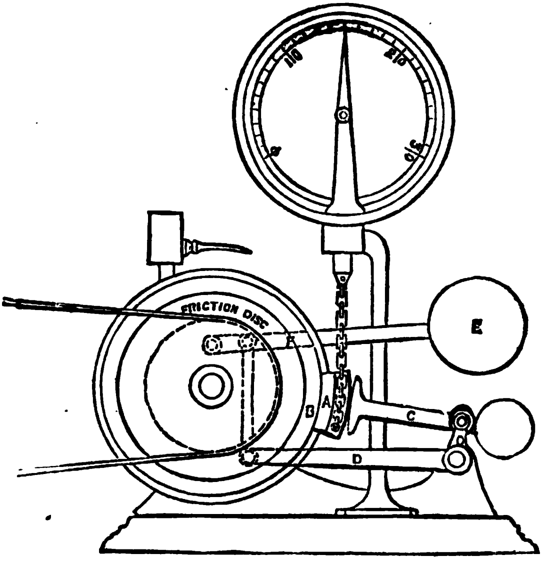


Fig. 10.

may in this way be very accurately measured by the position of the weight *K*.

This is not a very complete instrument, nor is it, as constructed, capable of giving very accurate determinations.

In Napier's machine, fig. 10, there is a wheel, *B*, of which the smooth, wide rim is pressed by a brake-block, *A*, which is forced against it with any desired amount of pressure by the action of weighted levers *D* and *F*. The effort of the wheel to carry the block around is resisted by another weighted lever, *C*, and by it the friction is measured.

Another machine, fig. 11, which has been well known abroad for many years and has recently been introduced to some extent in the United States, is that of Messrs. Ingham & Stapfer. It consists of a shaft running in two bearings and carrying a third journal between them. This latter has adjustable bearings, which are set up to any desired pressure by weighted levers.

A thermometer in the top brass enables the heating of the bearing to be observed. In this machine the friction cannot be measured; but the durability of an oil and its effectiveness in keeping a bearing cool can be observed. The machine has been extensively used in Europe, where Messrs. Bailey & Co., of Salford, have been building it many years. It has been made in the United States by Mr. Ashcroft, of Boston, and is here known by his name. A somewhat similar, but much larger, machine has been used at the Brooklyn Navy Yard ten years or

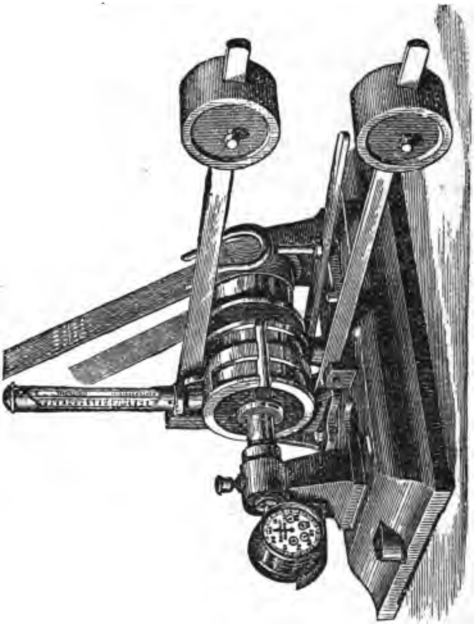


Fig. 11.

more, and an elaborate investigation was made there by Messrs. King, Stivers and Price, of the United States Navy Engineer Corps.

The next sketch, fig. 12, exhibits a modification of the Bailey machine as proposed in testing the durability of an oil.

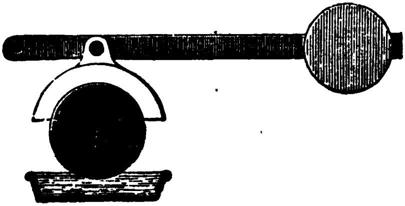


Fig. 12.

The tank (see below the journal) contains a quantity of oil which is carefully weighed at the beginning of the test and again after several hours work, when a portion will have been worn away or oxidized.

Fig. 13, shows the same machine as applied to test the solid lubricants, as lard and tallow.

Fig. 14 illustrates Crossley's dynamometer for measuring spindle friction when oils of various qualities are to be compared, as the instrument is made by Bailey.

It consists of a small, neatly made, transmitting dynamometer, through which the spindle or spindles are driven, which indicates, by means of a pointer traversing an arc, the force with which friction resists revolution in cases compared. This method has been adopted in the determination of the relative resistance in the machine in use at Cleveland, to be hereafter referred to.

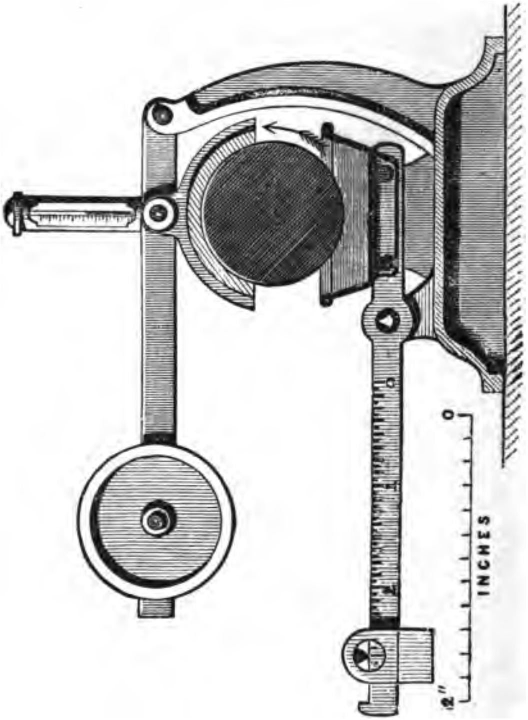


Fig. 13.

Still another very simple machine designed by Bailey is seen in fig. 15.

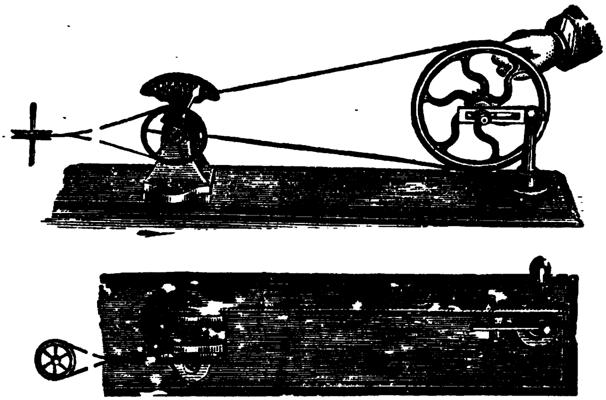


Fig. 14.

The pendulum carries a link at a point about one-third its length below the point of suspension, which link moves a little block of brass on the table set at the same height and supported by a bracket carried by the main standard of the machine. The lower end of the pendulum traverses a suitably graduated arc.

The test consists in applying a drop of the oil between the block and the table and noting the number of vibrations made before stopping.

Among other forms of machines should be mentioned that of the Lake Shore & Michigan Southern Railway,* at Cleveland, which consists of a railroad axle driven at standard speed and loaded properly. It is fitted with a counter and a thermometer, and the power required to drive

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* Illustrated in the "Railroad Gazette" of June 15, 1877.

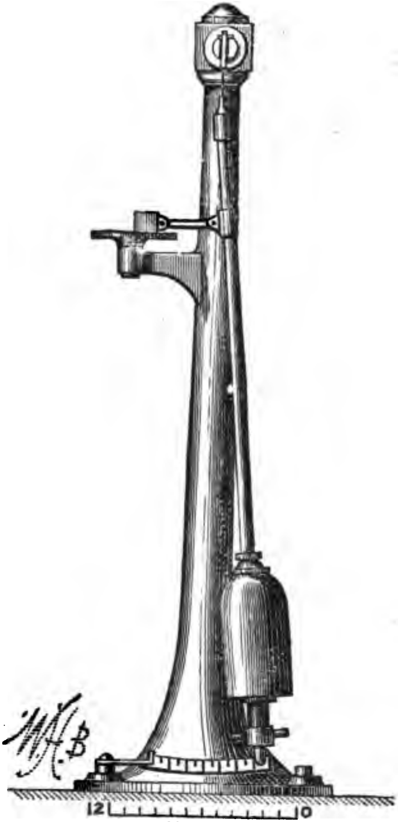

Fig. 15.

it is measured by a dynamometer. Some good work has been done on this machine.

A somewhat similar apparatus has been used at the Great Western Railway Company's works, at Hamilton (Canada), but without dynamometer, and still another, similar to the latter, was used by Mr. A. H. Van Cleve in making a series of experiments for the Camden & Amboy Railroad some years earlier.

A modification of the McNaught machine which renders it far more useful than the original has been made by Mr. Hodgson,

A side elevation of this machine, representing some of the parts in sections, is shown by fig. 16, a front elevation by fig. 17, and a plan by fig. 18. It consists of a horizontal plate *A A*, figs. 16 and 17, attached to a vertical shaft, *B B*, which is driven by a pair of mitre wheels, *C* and *D*, the latter attached to the horizontal shaft, *D E*, on which are.a tight and a loose pulley, *F* and *G*, which are driven by a belt. The plate *A A* has an angular groove or receptacle in top, in which a corresponding plate, *H H*, bears. This plate is attached to the shaft *I I* so that they will turn together, but the shaft is fitted into the plate somewhat loosely, so that the plate *H H* can always bear on *A A* uniformly all round, and not be constrained by the shaft *I*, The oil to be tested is placed in the annular groove between the two plates, or in an oil-cup, *a*, attached to the top plate. On top of the shaft *I* a lever, *JJ′*, bears on the centre, *J*. Any desired pressure can be brought to bear upon the lever and shaft, and through the latter upon the plate *H H*, by means of a spring balance, *K*, which can be screwed down to any desired pressure by a thumb-screw, *b*. It is obvious that if a pressure is brought to bear on the two plates, as the lower one revolves, the friction between them will tend to turn the upper plate and the shaft *I* to which it is attached. This motion will be resisted by a lever, *L L'*, (shown in plan below, fig. 17) with a sector, *c d*, on the outer end. This lever is attached to the upper end of the shaft *I I*. A cord, *L′ f*, is attached to the sector at *c*, and wound around its outer edge, and it then passes over a pulley, *e e*, and passes downward, and is fastened at *f* to another spring balance, *M*. It is evident from this description that when the machine is put in motion the friction between the two plates will cause the upper one to turn, and this, by means of the lever *L* and the cord *L′ F*, will raise the spring balance *M* until the resistance of its spring is just equal to that of the friction between the plates. In this way the indications of *M* will always measure the friction between the plates and that due to the oil which is placed between them to be tested.

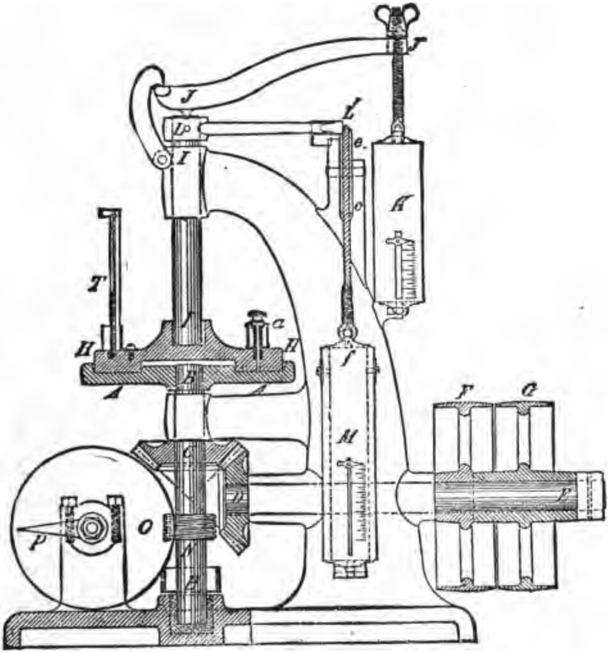

Fig. 16.

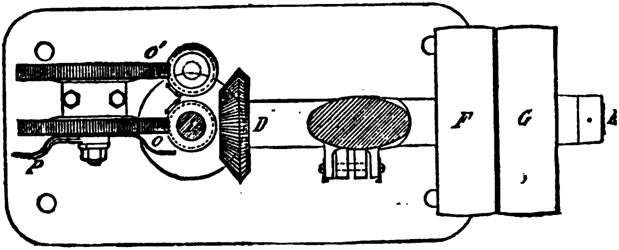

Fig. 18.

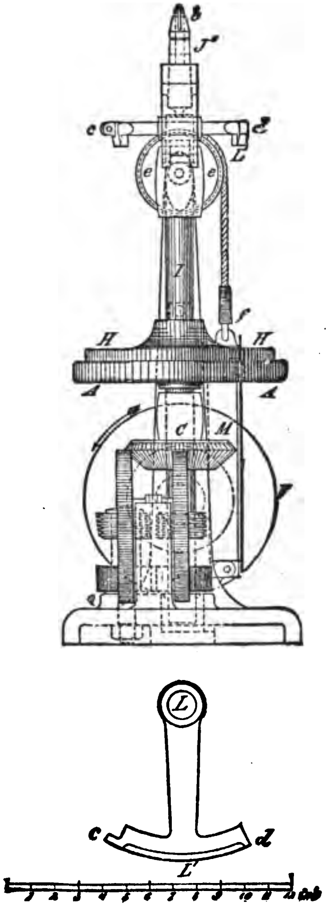

Fig. 17.

A thermometer, *T*, is attached to the upper plate, *H*, to indicate the rise in temperature, and the shaft, *B B*, has a worm gear, *N*, which works into suitable gear wheels, *O* and *O′*, which form a revolution counter, the index finger *F* indicating on a graduated face, which is not shown in the engraving, the number of revolutions made by the machine. From this description it will therefore be seen that this machine determines the coëfficient of friction of the oil, and the rise in temperature due to a certain amount of work done, which is determined by the pressure on the plates and the number of revolutions made in a given time.

This is the first of the illustrations in which all the required conditions can be introduced. Here the oil may be introduced in standard quantity, under the proposed pressure, and the machine can be driven at the required speed; while the thermometer and the spring balance show the temperature, and that more important figure the amount of friction. The machine might be so proportioned as to give the coëfficient of friction, although it might be a nice matter, perhaps, to obtain the exact measure.

57.—Lieut. Metcalfe, of the U. S. Army Ordnance, in experiments made at the Frankford Arsenal* in 1873, on axle and trunnion friction, determined the time required to raise the temperature a given amount with each of several oils. The following are the values for sperm, whale and lard oils, under a pressure of about 20 pounds per square inch, and a velocity of rubbing of about 800 feet per minute. The journal was of iron, the bearing of bronze. Three trials were made:

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* Ordnance Notes No. LXXXIV. Washington, July 15th, 1878.

TIME.

Springfield Sperm	139 seconds.
" Lard	102 "
Frankford Whale	107 "
" Lard	105 "

Lieutenant Metcalfe next adopted Rankine's method of noting the time required by a fly-wheel running loosely on a shaft to lose a given quantity of energy while stopping under the opposing efforts of its own inertia and the frictional resistance of its lubricated bearing on the stationary axle. From this he deduced the coefficient of friction thus:

The energy thus destroyed is

$$Q = \frac{MK^2}{2}\Theta^2$$

in which M is the mass $\left(\frac{Wt.}{32.2}\right)$ of the wheel, K its radius of gyration, and Θ is the initial angular velocity.

The work of resistance by friction is $Q^1 - Q$ and is measured by

$$Q^1 = 2F\pi RN = \frac{MK^2}{2}\Theta^2$$

and

$$F = \frac{MK^2\Theta^2}{4\pi RN}$$

in which F is the effort of friction resisting motion, R the radius of the shaft or journal, and N the total number of revolutions made while stopping. The mean velocity Θ' is one-half the initial velocity Θ. Then

$$F = \frac{MK^2\Theta^2}{4\pi RN} = \frac{4MK^3\pi N}{R\ S^2}$$

where S is the time of retardation in seconds.

$$f = \frac{F}{W} = \frac{F}{M_g} = \frac{4K^4\pi N}{RS^2_g} = C\frac{N}{S^2}$$

in which last expression C is a constant to be determined for any wheel used.

In Metcalfe's experiments the pressure was about 100 pounds per square inch, and whale oil gave $f = 0.015$ to $f = 0.016$.

The average revolutions were 53 per minute.

At the light pressure of the ordinary work of gun-carriage wheels, their coëfficients became:

Values of f for low pressures (Metcalfe), sperm oil, 0.088; castor oil, 0.028; axle grease, 0.030.

58.—THURSTON'S APPARATUS AND EXPERIMENTS.—I now come to the description of my own work in this department of practical research. When, in the preparation of my lecture on subjects of special importance to the engineer, I came to the consideration of this matter, I found that comparatively little had been done to determine the amount of friction under the every-day conditions to which we are accustomed at the present time. I found that nothing of any considerable importance had been done since the time of Morin's experiments, and that no accurate determination of the amount of friction of lubricated surfaces had ever been made at pressures, such as 500 and 1,000 pounds to the square inch, which I had often observed in my own practice and in that of other engineers. No attention seemed to have been paid to the great difference in the percentage of friction which my experience and that of others had taught me was due to varying pressure.

Those of us who have been accustomed to the handling of steam engines and other machinery have noticed—I have often—the extreme ease with which a crank "passes its center" under the heaviest pressure, and the freedom with which the most ponderous fly-wheel turns in its bearing when in motion. No one can believe that the coëfficients—0.05 and "0.03 under the most favorable conditions"—given by the leading authorities, as determined by observation of light pressures, can be even approximately correct for these heavy loads; were they thus correct, it is evident that the amount of work lost in the friction of heavy machinery must be simply immense.

I found that the determination of the amount of friction had, of late years, been seldom attempted, but that the simple measurement of the heating by means of machines of the Ingham & Stapfer class had been relied upon alone, and that results obtained were of value only by comparison. I therefore endeavored to devise a machine which should not only exhibit the heating of a lubricated journal under pressures and speeds variable at will, but one that should also give with great accuracy, and at the same time, the more delicate but much more important measures of the amount of friction. It was also desirable that the machine should give not only a measure of the resistance due to friction, but an exact measure of the percentage which that resistance bore to the total load on the journal; in other words, it should give directly and precisely the value of that "coëfficient of friction" which I defined at the beginning of these lectures.

I succeeded in the invention of such a machine, but, although I may claim to be the inventor of this machine, which is, I think, the first in which *all* the conditions of actual practice can be introduced and from which all the desired measures can be obtained, I must credit a student of the Class of 1873 of the Stevens Institute of Technology (Mr. J. A. Henderson, now of the United States Navy Eugineer Corps) with the production of this graceful and thoroughly satisfactory design.

It is a custom, in that department of the Institute over which I have the honor to preside to assign the students problems—*projets*, as the French engineers call them—in which a general description of the machine to be made, and of its work, is given; and they are expected to produce a complete and satisfactory design with description and working drawings. This machine was thus designed, and it was built from the drawings thus furnished without a single mistake which could be attributed to the designer.

59. The construction ot the machine is best shown in figs. 19 and 20 below.*

At *F* is the journal on which the lubricating material is to be placed for test. This journal is on the overhung extremity of shaft *A*, which is carried in bearings, *BB'*, on a standard, *DD'*, mounted on a base plate, EE′. The shaft is driven by a pulley, *C*, at any desired speed. A counter is placed at the rear end of the shaft to indicate the number of revolutions. Usually, the shaft is driven at a fixed speed, corresponding to the velocity of rubbing surfaces approximating that of journals on which it is proposed to use the the oil. The test journal, *F*, is grasped by bearings of bronze, *GG′*. and with a pressure which is adjusted by the compression of a helical spring, *J*. This spring is carefully regulated, and the total pressure on the journal and the

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* From the "Scientific American."

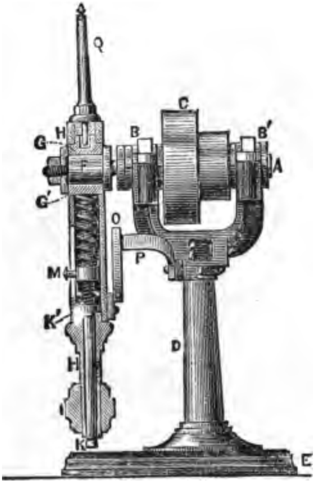

Fig. 19.

pressure per square inch are both shown on the index plate, *NN′*, by a pointer, *M*. Above the journal is a thermometer, *QQ′*, of which the bulb enters a cavity in the top "brass," and which indicates the rise in temperature as wear progresses.

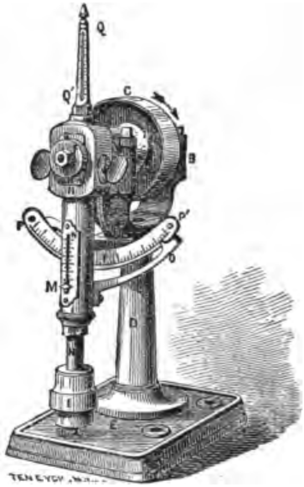

Fig. 20.

The "brasses," thermometer and spring are carried in a pendulum, *H*, to which the ball, *I*, is fitted; and the weights are nicely adjusted in such a manner that the maximum friction of a dry but smooth bearing shall just swing it out into the horizontal line. The stem, *KK′*, of the screw, which compresses the spring, projects from the lower end of the pendulum, and can be turned by a wrench. A pointer, *O*, traverses an arc, *PP'*, and indicates the angle assumed by the pendulum at any moment. This angle is large with great friction, and very small with good lubricating materials. This arc is carefully laid off in such divisions that dividing the reading by the pressure shown on the index, *NN'*, gives the corresponding coëfficient of friction.

The figures on the arc are the measure of the actual resistance of friction on the surface of the journal in pounds. Dividing this frictional resistance by the total load gives, as by the definition originally given, the exact value of the coëfficient. As there is no intermediate mechanism, this measure is obtained without possible error, and, as the resisting moment changes very rapidly at low angles, great precision of measurement is obtained, as will be seen when the results of experiment are stated. The machine can also be arranged to give readings of this coëfficient directly.

The THEORY OF THE MACHINE is as follows:

Let R equal radius to center of gravity of pendulum;

F equal effort due to weight of arm;

r " radius of journal;

l equal length of journal;
w " weight of pendulum complete;
P " total pressure on journal;
p " pressure per square inch of longitudinal section;
T equal tension on spring;
Θ " angle between arm and a perpendicular through axis;
f equal co-efficient of friction;
Q " total friction.

When Θ is equal to 90°,

$$FR = Qr \qquad (1).$$

And when any other angle,

$$FR \sin. \Theta = Qr \qquad (2).$$

Solving equation (2) with respect to Q,

$$Q = \frac{FR \sin. \Theta}{r} \qquad (3).$$

The pressure per square inch is

$$w = \frac{FR \sin. \Theta}{rP} \qquad (4).$$

The coefficient of friction is

$$p = \frac{P}{4lr} = \frac{2T + w}{4lr} \qquad (5).$$

from this last equation the graduations on the right-hand side of the index-plate are deduced.

From the equation

$$N = 4plr \qquad (6)$$

the numbers on the left-hand side are determined.

By substituting in equation (1) the value of Q, in terms of the coëfficient and total pressure, it becomes

$$FR = f(4plr)r \ldots\ldots\ldots\ldots (7).$$

Solving with respect to f, equation (7) becomes

$$f = \frac{\frac{FR}{r}}{4plr} \ldots\ldots\ldots\ldots (8).$$

From the numerator of the second number of equation (8) the graduations on the arc are deduced.

In applying the foregoing equations to the machine seen in the engraving, the following numerical values are given to the respective symbols:

$F = 2.5$ lbs; $R = 10$ in.; $r = .625$ in.; $l = 1.5$ in.; $4lr = 3.75$ sq. in.; $w = 6$ lbs. Also, a compression of $1\frac{3}{8}$ inches of the spring corresponds to a tension of 100 pounds; hence, for each pound's tension the spring will be compressed .01375 of an inch.

The graduations on the right-hand side of the scale are obtained from equation (5):

$$p = \frac{2T + w}{4lr} \ldots\ldots\ldots (4).$$

The first graduation will naturally be that value of p when T is equal to O, which value is **1.6.**

The speed of the machine, when the belt is upon the largest pulley of the cone, *C*, should be that which will give at the surface of the testing journal, the least speed of rubbing, which is usually to be adopted.

The figures on the arc *P P'*, traversed by the pointer *O*, attached to the pendulum, are such that the quotient of the reading on the arc *P P'*, by the total presure read from the front of the pendulum at *M N*, gives the "coëfficient of friction," *i. e.*, the proportion of that pressure which measures the resistance due to friction.

A printed table is furnished with each machine, giving these coëfficients for a wide range of pressures and arc-readings.

60. *To determine the lubricating quality*, we remove the pendulum *H H*, from the testing journal *G G'*, adjust the machine to rnn at the desired pressure, by turning the screw-head *K* projecting from the lower end of the pendulum, until the index *M* above shows the right pressure, and adjust it to run at the required speed by placing the belt on the right pulley, C.

We then throw out the bearings by means of the two little cams on the head of the pendulum *H*, in the small machine, or by setting down the brass nut immediately under the head in the large machine; we next carefully slide the pendulum upon the testing journal G

G′, and see that no scratching of journal or brasses takes place.

Then we oil the journal through the oil cups or the oil holes, set the machine in motion, running it a moment until the oil is well distributed over the journal.

Next we stop the machine; loosen the nut or the cams which confine the spring, and, when it is fairly in contact and bearing on the lower brass with full pressure, turn the cams or the brass nut fairly out of contact, so that the spring may not be jammed by their shaking back while working. We now, start the machine again and run until the behavior of the oil is determined, keeping up a free feed throughout the experiment.

At intervals of one or more minutes, as may prove most satisfactory, observations and records are made of the temperature given by the thermometer, *Q Q*, and the reading indicated on the arc *P*, of the machine, by the pointer *O*. When both readings have ceased to vary, the experiment may be terminated.

The pendulum is then moved, the pressure of the spring being first relieved, and the journal and brasses cleaned with exceedingly great care from every sign of grease; special care is taken to have no particle of lint on either surface, or any grease in the oil cups or oil passages.

A comparison of the results thus obtained with several oils will show their relative values as reducers of friction.

If the lubricant is to be used at high temperatures, a corresponding temperature is given to the bearings by means of a Bunsen flame.

Steam Cylinder Lubricants are tested upon bearings heated to a temperature corresponding to any desired steam pressure. When the maximum temperature has been attained, the flame is removed, and the behavior of the oil noted as the temperature falls to 212° F., which corresponds to atmospheric pressure or to zero on the steam gauge. Any effervescence or excessive friction at the higher temperatures condemns the lubricant. For comparison, our custom is to take the average of the coëfficients of friction for temperatures ranging from 340° F. —corresponding to a gauge pressure of 104 pounds—to 212° F.

In each case we record in tables like the blanks —of which a copy is given on the next page— which are sent with the machine:

1. The pressure and speed of rubbing at each trial; 2. The observed temperatures; 3. The readings on the arc of the machine; 4. The calculated coëfficients of friction.

We enter at the end of the trial the average and the minimum coëfficients, and the total distance *rubbed over* by the bearing surfaces.

Record of Tests of Lubricants.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING,

Stevens Institute of Technology.

Laboratory No............. *Original Mark*............ *Source*............

Composition..
....
....
Investigation..
....
....
....

$$\text{Coëfficient of Friction} = \frac{\text{Friction in Pounds}}{\text{Total Pressure.}}$$

No. of Test................	....	......	......
Pressure on Journal, lbs. per sq. inch.	....	......	......
Total Pressure on Journal, lbs......	....	......	......
Amount of Oil used on Journal, m.g.	....	......	......
Average Coëfficient of Friction.....	....	......	......
Minimum " " "	....	......	......
Total No. of Revolutions.........	....	......	......
Total No. of Feet traveled by rubbing surface	....	......	......
Elevation of Temperature, max.....	....	......	......

Time Minutes.	Revolutions.	Temperature.	Friction Pounds.	Coëfficient of Friction.	Time Minutes.	Revolutions.	Temperature	Friction Pounds.	Coëfficient of Friction.	Time Minutes.	Revolutions.	Temperature.	Friction Pounds.	Coëfficient of Friction.

61. *To determine the Liability of the Oil to Gum.*—The bearings are lubricated with a definite quantity of the oil, and the machine run a certain number of revolutions. The temperature of the bearings and the friction at the end of this period are noted. Both journal and brasses are then removed, placed under a glass receiver which excludes the dust yet permits the entrance of air, and are left there for any desired length of time. At the end of that time the bearings are replaced in the machine and the latter is run until the temperature of the bearings is the same as at the previous trial; the friction is then again noted. Any increase of friction above that previously observed must be due to the gumming of the lubricant. For the machine described, the standard quantity of the lubricant is 16 milligrams, which is ample to afford perfect lubrication of the bearing surfaces during the trials. The number of revolutions at the first trial is 5,000; it may, however, vary considerably without affecting the results so long as it is too small to affect the wearing qualities of the lubricant, as within this limit the friction remains constant with a constant temperature. Changes in temperature and friction always accompany each other; it is for this reason that great care is taken to obtain the same temperature of bearing at each trial.

To determine Durability, we proceed as in determining the friction, except that the lubricant should not be continuously supplied, but should be fed to the bearing a small and definite portion of time—say a drop for each two inches length of journal. Extreme care should be taken that each portion actually reaches the journal and is not lost, either in the oil-hole or by being wiped off the journal, and that the portions applied are *exactly* equal.

When the friction, as shown by the pointer *O*, has passed a minimum and begins to rise, the machine should be carefully watched, and should be stopped either at the *instant* that the friction has reached double the minimum, or when the thermometer indicates 212° F.; or else another portion of the lubricant should be then applied to the journal.

This operation should be repeated until the duration of each trial becomes nearly the same; an average may then be taken either of the time, of the number of revolutions, or of the distance rubbed over by the bearing, which average will measure the durability of that lubricant.

Next, we carefully clean the testing-journal, and proceed as before with the next oil to be tested.

In making comparisons we always test the standard, as well as the competing oils, on the same journal and under *precisely* the same conditions.

When testing an oil to ascertain its "durability" or endurance, a certain quantity, which is determined by experiment, is placed upon the journal, in all cases, and the test is continued until a limit is reached which is considered by the experimenter to be that of the valuable or safe use of that quantity of the lubricant under the conditions of the trial.

Until my own work began, it was the universal custom, I think, to continue the trial until the temperature of the bearing, as indicated by the thermometer, attained a certain point, as 120° or 200° Fahr., and to take the number of revolutions of the journal, or the number of feet traversed, up to that point, as a measure of endurance.

The real endurance, however, of the lubricating material bears no definite proportion to the range of temperature thus observed.

A better method is probably that adopted by the boards of U S. Naval Engineers, sometimes appointed to test oils at the navy yards. By this method, the quantity of oil required to keep down the temperature of journal to a certain figure, as 110° or 115° Fhr., during a definite period, as one hour, five hours, or twenty-four hours, is measured, and the endurance is taken as inversely proportional to these amounts, My own method is quite a different one. I consider the endurance of a lubricant to be measured by the length of time that it will continue to cover and lubricate the journal, and prevent abrasion.

When an oil is placed upon a journal, and there subjected to wear without renewal, it gradually assumes a pasty or gummy condition, slowly losing its lubricating power, and finally either increases friction to an objectionable extent, or oftener becomes so far expended as to permit the two rubbing surfaces to come in contact. It has been my custom to run until this occurs, and then to take the length of the run as a measure of the endurance of the oil.

It is extremely difficult to obtain successive measures of similar value by this method; but by taking an average of several—or many, if necessary—successive trials, the true measure of the endurance of lubricants can be obtained with any desired or necessary accuracy, This method, it should be observed, involves far more risk of injury to the journal than the other, and this necessitates, sometimes, considerable loss of time in bringing the rubbing surfaces back into good condition again before going on to make other tests. The determination of the real value of the lubricant is usually of sufficient importance to justify whatever time, trouble and expense may be thus incurred.

We are compelled to be exceedingly careful of the testing journal. A scratch will alter the conditions, sometimes, to a measurable degree. For nice work, the size of the drops is very carefully preserved constant. It is sometimes weighed on a chemist's balance. For rough work, a dropper, such as is used for medicine, with careful handling will do very well. I have had very good work done by dropping the oil from a No. 8 wire, filed smoothly to rather a blunt point. Dipping it into the oil, the first drops, when held vertical, are variable, but, after a half minute or so, they become uniform. We use the drop that falls after the expiration of three-fourths of a minute. The wire yields drops of sperm, at that instant, weighing eight milligrammes. We are always careful to see that the testing journal has a little end-play in its bearings, and keep it moving, during the test, to keep the oil distributed.

Many of our railroad companies, as well as other consumers of oil, are now regularly testing in this or some less thorough manner, and some of them are saving immense sums by this simple plan. The most complete system is probably that of the Pennsylvania Railroad Company, as practiced by Dr. Dudley in the laboratory at Altoona, where all the materials used on the road, properly subject to such examination, are tested, including their iron and steel, etc., as well as their lubricants.

In the Mechanical Laboratory of the Stevens Institute of Technology all results are entered in a set of record-books, where they are permanently preserved for the use of the Institute and for the accommodation of those having the work done. The results of test are furnished the latter on printed blanks which are similar to the pages of the record-books.

62. THURSTON'S RAILROAD MACHINE.—The small machine gave such results as to encourage me to design a large one especially fitted for railroad work, and one was subsequently built for the Stevens Institute of Technology, and others for the Pennsylvania Railroad laboratory at Altoona, and other roads.

The journal is of standard car-axle size, 3¼ inches diameter and seven inches long. The speed is intended to be adjusted to speeds varying from that of a twenty-six inch engine-truck wheel at sixty miles an hour down to that of a forty-two inch wheel running fifteen miles an hour. The pressures are adjustable from a few pounds total pressure up to 400 pounds per square inch, or a load of nearly 10,000 pounds on the journal.

Fig. 21 is a side elevation of the larger machine, with the journal and pendulum in section, and fig. 22 a front elevation. It consists of a shaft, *A B*, which is driven by a cone pulley, *C*, the whole mounted on a cast-iron stand, *D*, terminating in a forked end at the top, with two bear-

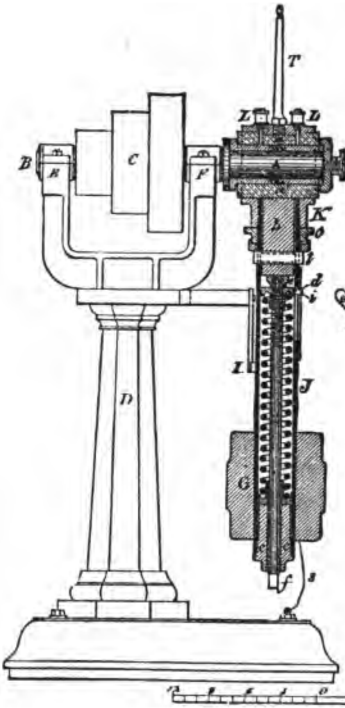

Fig. 21.

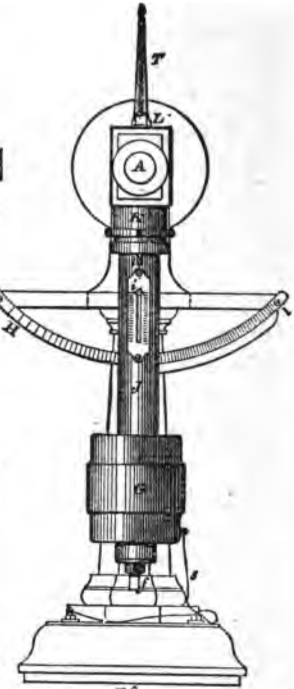

Fig. 22.

ings, *E* and *F*, in which the shaft runs. The shaft projects beyond the journal *F*, and the projecting part *A* is provided with a sleeve or bushing, *m m*, the outside of which forms a journal on which the tests of oil are made. A pendulum, *A G*, is suspended from this journal with suitable bearings, *a a*, which work on the journal *m m ;* a heavy weight, *G*, is attached to the lower end of the pendulum. It is evident that the friction on the journal *m m* will have a tendency to move the pendulum in the direction of the revolution of the shaft, and that the greater the friction on the journal the farther will the pendulum swing. A scale or dial, *H I*, is attached to the stand, and the distance the pendulum swings may be read off on this scale, which thus indicates the coëfficient of friction of the lubricant on the journal. In order to get any desired pressure of the bearings on the journal, the pendulum is constructed as follows: A wrought iron pipe, *J*, which is represented in fig. 21 by solid black shading, is screwed into the head *K*, which embraces the journal and holds the bearings *a a* in their place. In this pipe a loose piece, *b*, is fitted, which bears against the under journal-bearing *a'*. Into the lower end of the pipe a piece, *c c*, is screwed with a hole drilled in the centre through which a rod, *J*, passes, the upper end of which is screwed into a cap, *d'*; between this cap and the lower piece, *c c*, a spiral spring shown in section in fig. 21 is placed.

The upper end of the rod has a cap, *e*, in which it turns and which bears against the piece *b*, which in turn bears against the bearing *a'*. If the rod is turned with a wrench applied to the square head at *f*, it is obvious that the cap *d* will be either drawn down on the spiral spring, which will thus be compressed, or it will be moved upward, and the spring will thus be released, according to the direction in which the rod is turned. If the spring is compressed, its lower end will bear against the under cap and on the piece *c c*, by which the pressure will be transmitted to the pipe *J*, and thence to the head *K*, and from that on the upper journal-bearing *a*; while at the same time the upper end of the spring bears against the cap *d*, which, being screwed on the rod *f*, transmits its pressure upward to the cap *e*, and from that to the loose piece *b*, and from that to the upper journal-bearing *a*. It will thus be seen that any desired pressure within the limits of the elasticity of the spiral spring may be brought upon the journal and bearings by turning the rod *f*. The piece *b*, has a key, *l*, which passes through it and the pipe *J*. This key bears against a nut, *o*, which is screwed on the pipe, its object being to provide a ready means of relieving the journal of pressure by simply turning the nut *o* when it is desired to do so. An index, *i*, is attached to the spiral spring so as to show the position of the latter. The oil is fed to the journal by means of oil-cups, *L L* on the top of the head *K*, and a thermometer *T* is attached between the two cups, and from it the rise in temperature is observed. A cord, *s*, is attached to the pendulum to prevent it being thrown beyond the limits provided for it.

The machine represented by figs. 21 and 22 is the largest size built, and is the one which is furnished for testing oil for railroads.

Some slight modifications have since been made, as in the cone-pulley and in the substitution of a large relieving nut under the head of the pendulum for the two cams used to remove the load in the smaller machine; but in the main the description of the one will apply to the other.

It will be seen that the friction is modified by all differences in the material of the journal and its bearings, as well as by pressure, speed of rubbing, temperature and freedom and uniformity of lubrication, and we can therefore readily appreciate the necessity of testing the lubricant under the actual conditions proposed in its use.

63. EARLIER RESEARCHES.—Before giving these results, however, I will give those of some earlier investigations, in which the friction was not determined, but in which the value of the lubricant is assumed (improperly) to be determinable simply by observing its durability and its effect upon the thermometer. In making experiments of this kind, Bailey proposes that all should begin at the same standard temperature —say 60° F.—and should terminate at the same

point, which he would make 200°. He enters the data, as obtained, on a record sheet thus arranged:

Name of Oil.	Price.	Total Rev. to. 200° F.	Temp. of Atmosphere.	Rev. per Degree.

In a test to determine the gumming of oils, Wheeldon obtained the following table:*

RESISTANCE TO OXIDATION.—WHEELDON.

	Name.	Price.	Rev.	Temperature.	Elevation of Temp.	Rev. pr. degree.
1st day[1]...	No. 1 Ox.	5/6	13,005	From 80° to 200°	120°	108
2nd day[2]..	"		11,787	" 78 " 200	122	97
1st day[3]...	Sperm.	9/0	16,044	From 65 to 200	135	119
2nd day[4]..	"		13,104	" 62 " 200	138	95
1st day[5]...	Mineral.	3/6	11,831	From 65 to 200	135	88
2nd day[6]..	"		0	0 0	0	0

[1] First trial; new oil. [2] No fresh oil added. [3] First trial; new oil. [4] No fresh oil added. [5] First trial. [6] Second trial; after standing 24 hours the bearings were found glued to the test journal, and the machine refused to start.

The last of these trials could hardly, I think, have been made with the oil indicated by the name given. Mineral oils do not behave in that way.

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* Lecture by Mr. W. H. Bailey, Manchester, G. B.

Experiments made with the machine of Napoli* are reported to have given the following figure:

Name.	*Work in kilo's.*	*Time.*	*Rise in Temperature.*	*Remarks.*
Animal Oil (?).....	5,200	2 hrs.	10°	
Duron "	2,700	2 "	7	
Engine "	2,133	2 "	13	Composed of Mineral 0.25 Veg'ble 0.35 Fish 0.40
Whale "	7,000	5 "	10	
Colza (impure) oil.	1,000	2 "	0	Oil carbonized.

Coleman added caoutchouc to mineral oil to give it body, and tested it upon the leading wheels of a locomotive running between Edinburgh and Glasgow, finding that the rise in temperature, which was 29° with rape, was 21° with his mixed oil. He also obtained similarly favorable results on a 3-inch shaft, making 25,000 revolutions per hour under a load of a half ton. He found sperm to be the proper lubricant on spindles making from 2,000 to 10,000 revolutions per minute.

Tests made for the United States Navy Department, on the machine built at the Brooklyn Navy Yard, were reported to Admiral Bell, October 11th, 1866, by a board, consisting of Chief Engineer J. W. King and Assistant Engineers G. W. Stivers and A. Price. The machine was similar in character to that of Ingham & Stapfer, having, however, much larger journals.

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* "Am. Artisan," March 15th, 1873, p. 167.

These journals were 9¼ inches in diameter and 14 inches long.

The oils tested were supplied through an oil-cup in each journal-cap of standard navy size and form, and the amount so fed was adjusted until the journal-cap thermometer remained at a constant temperature of 116° Fahr., when sperm oil was used, the pressure being 9,400 pounds on each journal (72 pounds per square inch of longitudinal section of journal). This required a half-gallon of sperm in 25 hours. The same quantity of each oil was supplied, the pressure being gradually increased until the thermometer was maintained constantly at 116°. The maximum pressure thus sustained by each oil was considered to be a measure of its value.

The following are some of the results thus obtained:

Oil.	Pressure	
	Total.	Per sq. in.
Winter Sperm	9,400	72
Summer "	11,164	86
Winter Lard	8,000	62
Paraffine *	7,276	55
Petroleum* (light)	8,572	65
" (dark oil)*	9,500	73
Tallow oil	6,412	50
Mineral and Fish Oil	6,196	48

* Composition uncertain,

Four years later, another board, consisting of Assistant Engineers J. H. Morrison and J. W. Hollihan, reported the following results, using same machine and a similar method :

Oil.		Temperature.					
	Load,	Journal.	Air.	Oil thickens	Refuses to flow.	Solid.	S. G.
Sperm (natural)..	15,968	115° F.	76°	34°	26°	16°	0.761
Olive...........	14,900	116	75	50	18	6	0.933
Tallow..........	16,024	116	71	30	24	18	0.795
"	13,625	116	75	70	60	42	0.993
Lard	12,934	116	80	44	32	22	0.909

Tests made on the machine of the Lake Shore and Michigan Southern Railway and reported to the Master Mechanics' Association are stated, however, to give the following results :*

Fifty drops of each oil were used at one application, and the machine driven at a speed corresponding to 35 miles an hour, until the temperature shown by the thermometer rose from 60° to 200° F. The total number of revolutions was as follows :

ENDURANCE OF OILS—L. S. & M. S. R. R.

Castor.............	12,946 rev.	West Va.............	7,915 rev.
Paraffine...........	11,685 "	Sperm...............	7,912 "
Mecca (black)......	9,982 "	Tallow..............	7,794 "
Neatsfoot..........	8,277 "	Lard................	7,377 "

These results have been criticised; but the railroad continued the use of the cheaper oils, which may be taken as evidence that they are at least approximately correct.

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* "National Car-builder."

The most extended series of experiments of this character, and, in some respects, the most valuable ever obtained in this way, are those for which we are indebted to Mr. A. H. Van Cleve.* The test journal was 7 inches long and 6 inches in diameter, running in brass bearings, and driven by a 5 horse-power engine. The pressure was applied by a system of scale-beams, and the speed determined by a counter. The temperature was kept at from 96° to 100° F., and was shown by a thermometer inserted in the bearing. A record was kept of the pressure, the speed, the quantity of oil used and the power demanded to turn the shaft. In a second series of tests, a journal was used 6 inches long and $2\frac{3}{4}$ inches in diameter.

The results indicated that, in general, winter sperm sustains high pressures best; that the mineral oils used only kept the journal equally cool when from 2 to 5 times as much oil was used as of sperm. The pressure admissible varied inversely as the velocity of rubbing, and the consumption of oil varied in a similar ratio. These experiments occupied 14 months. The following table gives the principal facts:

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* "Scientific American," Dec. 9th, 1871.

FRICTION OF 7" x 6" JOURNAL.—VAN CLEVE.

OIL.	H. P.	Rev.	Press.	Temp.	Gills of Oil Pr. Hr.	Rel. Value.
Winter Sperm........	3.24 to 3.55	125 to 131	7,000 to 7,500	96° to 98°	0.68 to 0.82	1.00 to 0.91
½ Sperm—½ Lard.....	2.45	129	5,260	97	0.84	0.69
⅔ " —⅓ "	2.61	129	5,600	97	0.86	0.74
⅓ " —⅔ "	2.15	132	4,500	96	0.76	0.60
CAR-AXLE BEARING 6" x 2¾".						
W. Sperm.............	3.18	251	7,000	.95	0.25	0.91
LOCOMOTIVE AXLE.						
W. Sperm..............	....	130	7,000	97	0.40	....
"	....	100	7,200	94	0.26	....
"	....	70	8,000	94	0.18	....
"	....	60	9,800	94	0.14	....
"	....	130	7,500	98	0.36	....
"	....	100	7,500	96	0.25	....
"	....	70	8,000	91	0.19	....
"	....	60	9,500	90	0.10	....
Lard..................	....	130	4,000	78	0.31	....
"	....	100	5,200	75	0.18	....
"	....	70	5,500	73	0.12	....

64. THURSTON'S EXPERIMENTS AND RESEARCHES.—The tests made in the Mechanical Laboratory of the Stevens Institute of Technology, and of which the results have been given, have been principally made on the smaller of the testing machines here described.

They include tests of every kind of lubricant known to the engineer or the mechanic, and of very many which are not familiar, as well as of many that will never be used for this purpose. The following extended table exhibits the results of tests of some of these unguents. In making these tests, a cast-iron journal in fair condition* was used, the speed of rubbing was maintained at 750 feet per minute, and the same quantity of oil (32 milligrammes) was used at each trial.

The results of two series of tests are here. given. The rubbing surfaces were in *fair* condition, and it is uncertain how much gain would result from their further improvement—probably not very much, however.

65.—COËFFICIENTS OF FRICTION ON CAST-IRON JOURNALS.—THURSTON.

Volocity, 750 feet per minute; Temperature, 70° F.; Feed Intermittent.

NAME OF OIL.	POUNDS PRESSURE PER SQUARE INCH.							
	8		16		32		48	
GROUP I.	Avge.	Min.	Avge.	Min.	Avge.	Min.	Avge.	Min.
Natur'l Summer Sperm	.1720	.1330	.1627	.1083	.102	.0833	.1180	.1050
" Winter Sperm.	.2505	.1500	.1410	.1000	.0958	.0875	.0813	.0750
Bleached " "	.1920	.1583	.1600	.1330	.1172	.0916	.09907	.0944
" Summer Whale	.1866	.1333	.1383	.09166	.1109	.0874	.0881	.0777
Natural " "	.1986	.1500	.1482	.0916	.1316	.1086	.0951	.0722
" Winter "	.3296	.1833	.1902	.125	.0925	.0750	.1444	.1000
Bleached " "	.1979	.1333	.1916	.1333	.1086	.1000	.0993	.0705
Winter Lard Oil......	.2386	.1666	.1575	.1166	.1405	.1000	.1005	.0750
Extra Neats foot Oil..	.2242	.1500	.1621	.1000	.1166	.0916	.1138	.1055
Tallow Oil...........	.1840	.1500	.1460	.1000	.0935	.0750	.1166	.0844
Refined Seal Oil.	.1585	.1333	.1378	.1083	.1190	.0916	.0986	.0750
Bleached Winter Elephant Oil..........	.1928	.1333	.1650	.1083	.0862	.0791	.0766	.0611

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* The values quoted throughout these lectures, as well as by authorities generally, are higher than are probably those to be met with in machinery after long use in careful hands.

COEFFICIENTS OF FRICTION ON CAST-IRON JOURNALS—(*Continuea*).

NAME OF OILS.	POUNDS PRESSURE PER SQUARE INCH.							
	8		16		32		48	
	Avge.	Min.	Avge.	Min.	Avge.	Min.	Avge.	Min.
GROUP II.								
Olive Oil............	.1668	.1333	.1575	.1000	.1681	.1000	.0930	.0555
Cotton Seed Salad Oil	.2156	.1577	.1757	.1250	.1444	.1083	.0996	.0694
Palm Oil............	.2826	.1666	.2041	.1250	.1116	.0584	.1013	.0666
Rape Seed Oil.......	.1817	.1333	.1567	.1250	.1187	.0833	.1063	.0722
Elaine Oil...........	.2597	.2000	.1842	.1500	.1277	.0833	.1305	.1111
Linseed Oil..........	.1598	.1333	.1215	.0833	.1347	.0750	.0962	.0609
Peanut Oil...........	.1910	.1500	.1688	.1333	.10052	.0792	.0833	.0550
Refined Cotton Seed Oil................	.2125	.1666	.1401	.1249	.1166	.1000	.1100	.0800
Rosin Oil............	.2765	.2650	.2452	.1500	.1170	.0833	.1028	.0844
Cocoanut Oil.........	.1750	.1333	.1066	.0916	.1062	.0791	*.0794	*.0611
Cold Pressed Castor Oil................	.2375	.1916	.1380	.1125	.1026	.0708	.0944	.0722
GROUP III.								
Labrador Cod Oil.....	.2475	.1500	.1488	.1250	.1016	.0666	.0805	.0661
Tanner's Cod Oil.....	.2776	.2166	.1666	.1500	.0970	.0833	.0880	.0833
Menhaden Oil........	.2530	.1660	.1238	.1000	.1000	.0917	.1220	.1000
GROUP IV.†								
Mineral Sperm Oil....	.1875	.1333	.1604	.1416	.0861	.0791	.0944	.0944
Deod. White Lubricating............	.1537	.1500	.1583	.1500	.1277	.1125	.1277	.1277
Bleached Deod. Lubricating............	.1833	.1333	.2333	.1500	.1250	.1166	.1222	.1222
Unbleached Deod. Lubricating..........	.2550	.1500	.2067	.1500	.1275	.1250	.1555	.1444
Kerosene............	.2330	.2165	.1729	.1416	.1250	.1250	.1770	.1770
Crude Lubricating....	.1272	.1100	.1453	.1000	.1777	.1500	.1500	.1500
Paraffine.............	.2607	.2000	.1777	.1333	.1343	.1125	.2222	.2222
GROUP I.			SECOND SERIES OF TESTS					
Natural Winter Sperm	.2072	.1333	.1661	.1291	.1302	.0958	.1155	.0888
Bleached " "	.1755	.1166	.1678	.1291	.1083	.0958	.0811	.0750
Natural " Whale	.2369	.2166	.1250	.1000	.1000	.0750	.0777	.0666
Bl'ched Winter Whale	.1747	.1333	.1483	.1133	.1333	.0833	.0986	.0666
Winter Lard.........	.1959	.1583	.1770	.1250	.1095	.0666	.0758	.0666
Extra Neats foot.....	.1746	.1500	.1254	.1000	.1198	.0791	.1159	.1000
GROUP II.								
Olive Oil............	.1839	.1333	.1175	.0916	.0902	.0750	.1344	.0611
Refined Rape Seed (Yellow)...........	.1716	.1666	.1435	.1166	.1000	.0833	.0822	.0555
Winter Pressed Cotton Seed (White).......	.1259	.1166	.0981	.0833	.0983	.0666	.0861	.0750
Winter Pressed Cotton Seed (White).......	.1557	.1333	.1006	.0833	.0895	.0750	.0758	.0722
GROUP III.								
Menhaden Oil.......	.1637	.1333	.1685	.1083	.0982	.0625	.0963	.0888

* Values somewhat uncertain. † All mineral oils here described are of uncertain composition.

Oils of the second series were a distinct lot, No certainty exists that these oils were all pure; but it is probable that they were.

66. METHOD ILLUSTRATED.--To show how these figures were obtained, I will here give the results in detail and in the usual tabular form as given on trial of a good sample of winter-bleached sperm oil. It should be remembered, however, that precise agreement between two tests of even the same oil never can occur except by a rare accident, as the oil itself is never precisely alike throughout—sperm oil, for example, varying in quality with its purity and age, and with the age, sex, health and habits of the fish from which it was taken, &c., and the conditions of the journal and the other circumstances affecting the trial can rarely, if ever, be duplicated with absolute precision. These differences are not usually of practical importance, but the precaution is always taken to compare each oil tested with a standard pure sperm, carefully preserved, to be tested immediately before or immediately after the test of the oil to be examined.

DETAILS OF TEST.

BEST WINTER BLEACHED SPERM OIL.—THURSTON.

FIRST TRIAL.

Amount used upon the journal..............................332 milligrammes.
Speed of rubbing surface.......... ....736 ft. per min.
Pressure per square inch...8 lbs.
Total pressure...30 lbs.

Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.
At Start.	Deg. Fahr.				Deg. Fahr.				Deg Fahr.		
min.	75	0		39	160	3.5		79	190	5.5	
1	85	8		41	160	3.5		81	190	5.5	
3	120	7.5		43	163	3.5		83	195	5.5	
5	145	5.5		45	163	3.5		85	195	5.5	
7	160	5.5		47	163	3.5		87	200	5.75	
9	170	6		49	165	3.5		89	200	5.75	
11	178	6		51	165	3.5		91	205	6.5	
13	185	6		53	165	3.5		93	210	5	
15	190	5		55	167	4		95	205	4.5	
17	190	5		57	167	4		97	205	5	
19	193	5		59	168	4		99	197	5	
21	193	4.5		61	170	4		101	195	5	
23	190	4		63	170	4		103	195	5.5	
25	185	3	minimum. .10	65	170	4		105	197	5.75	
27	180	3		67	170	4		107	200	6.5	
29	175	3		69	175	5.5		109	200	6.5	
31	170	3		71	175	5.5		111	212	6.5	
33	168	3		73	180	5.5		113	216	6.5	
35	165	3		75	180	5.5		115	216	6.5	
37	165	3.5		77	185	5.5		117	220	5.5	
119	220	6.5		139	235	7		159	240	7	
121	218	6.5		141	235	7		161	240	7	
123	220	6.5		143	235	7		163	240	7	
125	220	9.5		145	238	7		165	243	7	
127	220	9.5		147	238	7		167	243	7	
129	230	7.5		149	238	7		169	243	7	
131	230	7.5		151	238	7		171	244	7	
133	232	7		153	240	7		173	245	7	
135	234	6.5		155	240	7		175	250	7	*Mean,*
137	234	7		157	240	7		177	260	7	0.1875

SECOND TRIAL.

Amount used upon the journal .... 332 milligrammes.
Speed of rubbing surface .... 736 ft. per min.
Pressure per square inch .... 16 lbs.
Total Pressure .... 60 lbs.

Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.
At Start.	Deg. Fahr.				Deg. Fahr.				Deg. Fahr.		
min.	70	0	* Minimum 0.133.	17	275	11.5		35	325	10.5	
1	80	15		19	290	11.5		37	325	11	
3	130	10		21	305	11.5		39	327	11.5	
5	170	10		23	315	11.5		41	333	11.5	
7	200	9		25	320	11.5		43	337	12	
9	215	9		27	320	9.5		45	342	15	
11	239	9		29	320	10		47	352	12	
13	250	8*		31	318	11.5		49	355	10	
15	262	9		33	322	10.5		51	350	10	
53	350	11		59	335	10		65	318	10.5	
55	350	10		61	325	10		67	325	10	av'ge,
57	340	10		63	318	9.5		68	325		0.1776

THIRD TRIAL.

Amount used upon the journal .... 332 milligrammes.
Speed of rubbing surface .... 736 ft. per min.
Pressure per square inch .... 32 lbs.
Total pressure .... 120 lbs.

Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.
At Start.	80	0		5	210	11.5	0.096 minimum.	11	295	15 to 25	
1	95	21		7	235	11.5		12*	320		av'ge,
3	170	15		9	260						0.1317

FOURTH TRIAL.

Amount used upon the journal..............................332 milligrammes.
Speed of rubbing surface..................................736 ft. per min.
Pressure per square inch..................................48 lbs.
Total pressure...180 lbs.

Time.	Temperature of Brasses.	Friction, Pounds.	Coefficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coefficient of Friction.	Time.	Temperature of Brasses.	Friction, Pounds.	Coëfficient of Friction.
At Start.	80	0		3	180	15	minimum,	7	285	30	
								8	320	to	av'ge,
1	100	20		5	235	16	.833	9†	345	40	.1194

RESULTS OF TRIALS OF AN OIL MARKED X AND ITS COMPARISON WITH STANDARD BLEACHED WINTER SPERM AND PURE LARD OILS.

In illustration of the method subsequently adopted in making a tolerably complete investigation, we have the following.

These oils were tested on a "Lubricant Testing Machine" of the "77" style, by the method already described-

The standard bleached winter sperm and a pure lard oil were tested with the X oil on the same bearing and under precisely similar conditions.

The following are records of data obtained during these tests:

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* Bearing dry, and grinding at the end of 12th min. † Bearing dry, and oil burning at the end of 9th min.

RECORD OF TESTS OF LUBRICANTS.

WINTER BLEACHED SPERM AND LARD OILS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

Laboratory Nos. 90 and 93; Original Marks, Standard Sperm, Penn. Lard; Sources, New Bedford and P. R. R.

Investigation to determine the Power of Reducing Friction; Coëfficient of Friction $= \frac{\text{Reading on Arc}}{\text{Total Pressure}} = \frac{\text{Pressure}}{\text{Friction}}$.

No. of Test, 1, 2, Sperm—1, 2, Lard; Pressure on Journal, lbs. per sq. inch, 50, 100, Sperm—50, 100, Lard. Total Pressure on Journal, lbs., 200, 400, Sperm—200, 400 Lard; Amount of Oil used on Journal, Continuous Supply; Average Coëfficient of Friction, .0050, .0037, Sperm—.0100, .0062, Lard; Total number of Feet traveled by rubbing surface per min., 237.3, 235.1 Sperm, 233.8, 229.2 Lard; Elevation of Temperature, max., 8, 10, Sperm—9, 12, Lard.

SPERM OIL.

Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.
At start		90	1.5		20		96	1		40		98	1	
5		93	1		25		97	1		45		98	1	
10		94	1		30		98	1		55		98	1	
15		95	1		35		98	1		60		98	1	

Test No. 2.

At start		90	2		20		98	1.5		40		100	1.5	
5		93	1.5		25		100	1.5		45		100	1.5	
10		95	1.5		30		100	1.5		50		100	1.5	
15		97	1.5		35		100	1.5		60		100	1.5	

Lard Oil No. 1.

At start		90	2		20		98	1.5		40		99	1.5	
5		93	1.5		25		99	1.5		45		99	1.5	
10		95	1.5		30		99	1.5		50		99	1.5	
15		96	1.5		35		99	1.5		60		99	1.5	

Test No. 2.

At start		90	3		20		98	2.5		40		102	2.5	
5		93	2.5		25		100	2.5		45		102	2.5	
10		95	2.5		30		102	2.5		50		102	2.5	
15		97	2.5		35		102	2.5		60		102	2.5	

RECORD OF TESTS OF LUBRICANTS.

WINTER BLEACHED SPERM AND LARD OILS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

Laboratory Nos. 90 and 93; Original Marks, Pure Sperm, Penn. Lard; Source, New Bedford and P. R. R.

Investigation to Determine the Durability of the Oil; Coefficient of Friction $= \frac{\text{Reading on Arc.}}{\text{Total Pressure.}} = \frac{\text{Friction}}{\text{Pressure.}}$

No. of Test, 1 Sperm, 1 Lard; Pressure on Journal, lbs. per sq. inch—75 Sperm, 75 Lard; Total Pressure on Journal, lbs. —300 Sperm, 300 Lard; Amount of Oil used on Journal, m. g.—8 Sperm, 8 Lard; Average Coëfficient of Friction——, Sperm, ——Lard; Minimum Coëfficient of Friction——Sperm,——Lard; Total No. of Revolutions—27,870 Sperm, 24,500 Lard; Total No. of Feet Traveled by Rubbing Surface—97,266 Sperm, 85,505 Lard; Elevation of Temperature, max. —35 Sperm, 55 Lard.

SPERM OIL.

Time Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.
At start.		65	3		60		100	4.5		77	26,560	100	6	
1		65	4		62		100	5			Re-distributed oil.			
5		70	4		63	23,010	100	6		79		100	4.5	
10		78	4			Re-distributed oil.				80		100	5	
15		85	4		65		100	3		82	27,590	100	6	
20		93	4		68		100	5			Re-distributed oil			
25		95	4		70	24,860	100	6		84		100	5.5	
30		98	4			Re-distributed oil.				85	27,870	100	6	
40		100	4		72		100	3			Re-distributed oil.			
50		100	4		75		100	5.5		87		100	6	

LARD OIL.

At start.		65	5	
1		65	6	
5		75	6	
10		85	6	
15		95	7	
20		100	8	
25		105	9	
30	11,120	110	10	
Re-distributed oil.				
32		110	5	
35		110	6.5	
38		113	7	
40		115	8	
43		118	9	
45		118	9	
50	17,810	120	10	
Re-distributed oil.				
52		120	5	
53		120	6	
55		120	7	
57		120	8	
58		120	8.5	
59		120	9	
60	20,660	120	10	
Re-distributed oil.				
61		120	5.5	
62		120	6.5	
63		120	7.5	
64		120	8	
65		120	9	
66	22,500	120	10	
Re-distributed oil.				
68		120	7	
69		120	8	
70		120	8.5	
72		120	9	
73	24,100	120	10	
Re-distributed oil.				
75		120	8	
76	24,500	120	10	
Re-distributed oil.				
78		120	10	

RECORD OF TESTS OF LUBRICANTS.

OIL MARKED X.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

Original Mark X.

Investigation to determine the Durability of the Oil; Coëfficient of Friction $= \frac{\text{Reading on Arc}}{\text{Total Pressure}} = \frac{\text{Friction}}{\text{Pressure}}$.

No. of Test, 1, 2; Pressure on Journal, lbs. per sq. inch., 75, 75; Total Pressure on Journal, lbs., 300, 300; Amount of Oil used on Journal, m. g., 8, 8; Total No. of Revolutions, 25,720, 27,040; total No. of Feet traveled by rubbing surface, 8976., 10136.9; Elevation of Temperature, max. 95, 115.

Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coefficient of Friction.
At start.		65	11		45		125	9		72	19,280	145	16	
5		85	10		48		125	10			Re-distributed oil.			
6		88	8		50		128	11		73		145	13	
10		95	8		53		128	12		74		148	14	
15		110	10		55		130	12		75		150	14	
20		120	11		60		135	12		80		150	14	
24	7,590	120	16		65		140	15		85		155	14	
	Re-distributed oil.				66	17,940	140	16		90		160	14	
27		120	8			Re-distributed oil.				92		160	15	
30		120	8		67		140	11		93	25,720	160	16	
35		120	9		68		140	12			Re-distributed oil.			
40		123	10		69		143	13		94		160	16	
42	11,920	125	16		70		145	14						
	Re-distributed oil.				71		145	15						

TEST No. 2.

At start.		65	10.5		47		153	15		60		165	13.5	
5		90	11.5		48	17,890	155	20		65		170	14.	
10		115	11.5			Re-distributed oil.				70		175	14.5	
15		130	11.		49		155	10		75	2,7040	180	20	
20		140	10.5		50		155	13			Re-distributed oil.			
40		150	10.5		51		158	14		77		180	20	
45		150	12		52		158	15						
46		150	13		55		160	13.5						

[The re-distribution occasionally effected to secure complete utilization was done with the tip of the finger of the observer.]

RECORD OF TESTS OF LUBRICANTS.

OIL MARKED X.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING STEVENS INSITUTE OF TECHNOLOGY.

Original Mark X. Composition—An unknown mixture of mineral and perhaps other oils with powdered graphite.
NOTE—Graphite separated when left undisturbed in my study.*

Investigation to determine Power of Reducing Friction ; Goëfficient of Friction $= \frac{\text{Reading on Arc}}{\text{Total Pressure}} = \frac{\text{Friction}}{\text{Pressure}}$.

No. of Test, 1, 2 ; Pressure on Journal, lbs. per sq. inch, 50. 100 ; Total Pressure on Journal, lbs. 200, 400 ; Amount of Oil used on Journal, Continuous supply ; Average Coëfficient of Friction, 0.206, 0.168 ; Minimum, .0200, .0125 ; Total No. of Feet traveled by rubbing surface, per min., 23,517, 2,305 ; Elevation of Temperature, max., 10, 40.

Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.	Time. Minutes.	Revolutions.	Temperature.	Reading on Arc.	Coëfficient of Friction.
At start.		90	5		20		98	4		45		100	4	
1		91	5		25		98	4		50		100	4	
5		95	5		30		98	4		55		100	4	
10		98	4.5		35		98	4		60		100	4	
15		98	4.		40		98	4						
							TEST NO. 2.							
At start.		90	15		20		128	5		45		105	5	
1		100	17		25		120	6		50		105	5	
5		130	20		30		110	5		55		105	5	
10		128	8		35		105	5		60		105	5	
15		128	10		40		105	5						

* Good plumbago oils should not give a precipitate, however long left undisturbed.

From the preceding logs of tests we deduce the following results and conclusions:

AVERAGE COËFFICIENTS OF FRICTION.

Lab. No.	Name of Oil.	Pressure per Square Inch.		
		100	50	Average.
90	W. B. Sperm................	.0037	.0050	.00435
	X	.0168	.0206	.0187
93	Lard.......................	.0062	.0100	.0081

The relative values of these oils in reducing friction, taking sperm oil as a standard, and giving it a value of 100, will be represented by the quotients obtained by dividing the coëfficients for sperm by those for each of the other oils, and multiplying by 100.

The following table gives these quotients:

RELATIVE POWER OP REDUCING FRICTION.

Name of Oil.	Pressure per Square Inch.		
	100	50	Average.
W. B. Sperm................	100	100	100
X..........................	22.	24.2	23.2
Lard.......................	59.6	50.	53.7

The speed was about 700 revolutions per minute (244.3 ft.), giving a speed ot rubbing surface corresponding to about 35 miles per hour for a 33-inch wheel in railroad service. Dividing the coëfficients for the oils by the coëfficient for sperm and multiplying by 100, we obtain the following tabulated figures as the relative amount of power consumed in using the respective oils.

RELATIVE POWER CONSUMED.

Name of Oil.	Pressure per Square Inch.		
	100	50	Average.
W. B. Sperm	100	100	100
X	481.	412.	429.8
Lard	167.6	200	186.2

As regards friction, sperm excels, lard stands next, and X next,

From the results of the tests of durability, we find the following:

DURABILITY, OR WEARING POWER.

	Revolutions.	*Ft. traveled.*
W. B. Sperm	27,870	9,726.6
X (average)	26,380	9,206.6
Lard	24,500	8,550.5

Taking bleached winter sperm oil as a standard, and assuming its value to be 100, the values of the oils as regards durability will be represented by 100 times the quoticnt obtained by dividing the number of revolutions or feet travelled of each oil by the runs for sperm. We thus obtain the following:

RELATIVE DURABILITY.

W. B. Sperm	100.
X	94.6
Lard	87.9

The figures in this last table are measures of the lengths of time that equal quantities of each oil would run, so that the greater the figures of this table the more valuable the oil.

The value of an oil may be taken as greater in proportion as the figures in the above table are greater, and as the figures in the table headed "Relative Power of Reducing Friction" are greater, so that combining the results given in both tables, the relative values of the oils, sperm oil being the standard and taken at 100, may be represented by one one-hundredth the product obtained by multiplying the figures in the last column of the table headed "Relative Durability" by those in the last column of the table, headed "Relative Power of Reducing Friction." The following are therefore the

RELATIVE VALUES OF THE OILS.

W. B. Sperm	100
X	21.9
Lard	47.2

SECOND TEST.

A second test consisted in cutting a square hole in the lower box and packing it with waste saturated with the oil to be tested. The oil to be tested was spread on the journal and a pressure of 100 lbs. per square inch was applied; the machine was then started and allowed to run until the friction had increased to double the least amount shown at any time during the test. Both the X and the lard oils were tested by this method. In each case 743 milligrammes weight of waste was used as packing. The waste was in each case thoroughly saturated with the oil and weighed before and after the test. In the case of X, the waste absorbed 4.806 grs. and contained 2.229 grs. at the end of the test, so that the oil consumed was 2.577 grs. In the case of the lard, 4 grs. were also absorbed by the waste; 7.265 grs. remained; so that the useful consumption was 2.735 grs. X ran 266,226 ft. = 54.2 miles per gramme consumed, with an average coefficient of friction of .0318, and lard oil ran 182,528.7 ft. = 34.5 miles per gramme consumed, with an average coëfficient of friction of .0244, the former excelling the latter about *sixty per cent.*

THIRD TEST.

A third test was made upon the "R. R. Standard Machine," and the following are the coefficients of friction obtained:

AVERAGE COËFFICIENTS OF FRICTION.

Name of Oil.	Pressure per Square Inch and Total.		
	150 lbs. 2629 total.	300 lbs. 5250 total.	Average.
W. B. Sperm................	.008	.0046	.0063
X	.024	.015	.0195
Lard	.009	.0059	.0075

67. FRICTION WITH VARYING PRESSURE. On examination of the tables given in article 64, we are at once impressed with the immense difference which occurs with variation of pressure. It is seen that, at a pressure of 48 pounds per square inch, the values are not far from those quoted by accepted authorities, but at the lower pressures, where the resistance is more due to viscosity than to true friction, the value of the coëfficient of friction immensely exceeds those familiar values.

It is instructive to compare these figures with those obtained at high pressures, with which object I give the table below.

Tested on a fine steel journal, with free lubrication, the figures become but a fraction of those already given.

Sperm, lard and West Virgina oil, thus tested, give:

COËFFICIENT OF FRICTION ON FINE STEEL JOURNALS.—THURSTON.

Name,	Pressure: Pounds per Square Inch.								
	4	10.	25.	150.	200.	250.	275.	300.	500.
Sperm	0.12	0.08	0.041	0.0090	0.0096	0.0086	0.0091	0.0046	0.0033
Lard	....	....	0.056	0.0136	0.0127	0.0110	0.0090	0.0059	0.0044
West Virginia ...	....	....	......	0.0120	0.0095	0.0081	0.0100	......	......

Here it is seen that the figures are as widely different from accepted values at high pressures as at low; but that the difference is upon the other side. At those pressures, therefore, which are most used in machinery, the resistance of friction is vastly less than we have been led to suppose. The fact that the journals were of steel instead of iron does not modify our conclusion. Steel, cast-iron and wrought-iron all give very nearly the same figures up to their limits of pressure.

The next table exhibits the results of experiment up to still higher pressures, and with other journals and bearings,

COËFFICIENTS OF FRICTION, OF MOTION AND OF REST.—THRUSTON.

(*a*.)—Cast Iron Journal and Steel Boxes.

Pressures Per Sq. Inch.	B. W. Sperm.			West Virginia.			Lard.		
	At 150 Feet Per Minute f.	At Starting f'.	At Instant of Stopping f''.	At 150 Feet Per Minute f.	At Starting f'.	At Instant of Stopping f''.	At 150 Feet Per Minute f.	At Starting f'	At Instant of Stopping f''.
50	.013	.07	.03	.0213	.11	.025	.02	.07	.01
100	.008	.135	.025	.015	.135	.025	.0137	.11	.0225
250	.005	.14	.04	.009	.14	.026	.0085	.11	.016
500	.004	.15	.03	.00525	.15	.018	.00525	.10	.016
750	.0043	.185	.03	.005	.185	.0147	.0066	.12	.02
1000	.009	.18	.03	.010	.18	.017	.0125	.12	.019

(*b*.)—Steel Journals and Brass Boxes.

Pressures Per Sq. Inch.	B. W. Sperm. At 150 Feet Per Minute f.						Lard. At 150 Feet Per Minute f.		
500	.0025						.004		
1000	.008						.009		

Temperature in all cases less than 115° Fahrenheit. Velocity of rubbing, 150 feet per minute.

		W. B. Sperm.	Lard.
Ratio of $\frac{b}{a}$ =		.75 for 500,	.77.
Ratio of $\frac{b}{a}$ =		.888 for 1000,	90

Studying this table, we see that the coëfficient rapidly diminishes with increase of pressure until a pressure of over 500 pounds per square inch is attained; the coëfficient, after passing a pressure of probably 600 to 800 pounds per square inch, increases, and at 1,000 pounds becomes about equal to that obtained at 100 pounds. It will be remembered that 500 or 600 pounds pressure is usually considered to be a limit not to be exceeded in general practice in machine construction.

Nevertheless, it is not uncommon to find as high pressures as 1,000 or even 1,200 pounds in the crank-pins of steam-engines. In such cases, however, the pins are almost invariably of steel, and the journals of good bronze—conditions which are less seldom met with elsewhere. There is also, in this case, as wherever a "reciprocating force" acts to move a piece, a condition which permits higher pressures to be successfully worked than can be reached elsewhere; the alternate application and relief of pressure occurring between journal and bearing at each change of direction of the driving force causes a release at such times which permits the oil to find its way between the rubbing surfaces, and its expulsion is not then fully effected before the succeeding relief of pressure again permits its renewal. A somewhat similar action is consequent upon the rise and fall of a locomotive or of a railroad car on its springs as it rapidly traverses even a smooth track.

Where, as in our testing-machine, under a fly wheel-shift, or in other machinery, this relief cannot take place, the limit of pressure is earlier met.

Referring again to the last table, it is seen that between 100 and 750 pounds the value of the coefficient may be obtained approximately by the expression

$$f = \frac{a}{\sqrt{P}}$$

in which a is a constant quantity and P is the pressure in pounds per square inch; for sperm oil a=0.080; for the best crude heavy mineral oil a=0.150, and for lard oil a=0.125* It will presently be seen that the law is modified by temperature and speed.

68. The following data were given by trials of two excellent kinds of grease, and of sperm oil, compared with them as standard.

COËEFICIENTS OF FRICTION OF GREASES.—THURSTON.

Steel Journals; Bronze Bearings. Velocity, 300 ft.

Lubricant.	Pressure—Lbs. per sq. inch.					Av.
	100.	200.	300.	400.	500.	
Sperm Oil.............	0.0141	0.0063	0.0049	0.0042	0.0039	0.006$_7$
Grease, No. 1..........	0.0249	0.0146	0.0125	0.0105	0.114	0.014$_0$
" No. 2..........	0.0188	0.0198	0.0160	0.0146	0.0175	0.017

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* These facts and deductions were published originally in a paper prepared in the spring of the year 1878, and read at the St. Louis meeting of the American Association for the Advancement of Science.

Their relative average values in reducing friction stand, therefore: sperm, 100; No. 1, 448; No. 2, 377, which figures would also represent their relative money values if estimated on that basis simply.

The method of variation with pressure already noted, is here again illustrated, although the mathematical expression has a different sort of constants, and the variation at this speed is more nearly as the inverse ratio of the cube root of the pressure.

69. FRICTION OF QUIESCENCE.—In the table last given is presented a set of figures which are both new and important. In the columns headed "At 150 feet per minute" are given the coefficient of friction at the several pressures as given when the rubbing surfaces are in motion at that relative velocity.

These are the common and most usually required figures. We have given in the other columns, however, values which are seen at a glance to be immensely greater, and of which the values vary by an entirely diffierent law.

The first set "at starting," are the well-understood coëfficients of friction of rest, varying with the pressure and with the nature of the unguent from 0.07 to 0.18. These values have, I think, never been determined before in this way, and possess great importance not simply intrinsically, but also as throwing some light upon the effect of motion upon the efficacy of lubrication. It is seen that they increase with the pressure, instead of diminishing as do the coëfficients of friction of motion, and that at the highest pressures their values become from ten to forty times the corresponding values of the latter.

It is thus seen that in the effort required to move heavy machinery, vastly greater force is demanded to overcome friction at the instant of starting than after motion has once commenced. I presume that every experienced engineer or mechanic has known instances in which this difference has been so marked as to cause great difficulty in starting a machine, which, once in motion, moved with comparative ease.

The method of variation of the coëfficient for rest is seen, by reference to the table, to be such that their numerical values may be approximately estimated for the cases here considered by the formula

$$f' = a'\sqrt[3]{P},$$

in which $a' = 0.02$ for sperm and heavy mineral oil, and $a' = 0.015$ for lard oil.*

The figures in the columns headed "At instant of stopping" were given while the machine was rapidly coming to a stop, after the driving-belt had been shifted to the loose pulley. They are, as would be expected, intermediate in value between the other figures, and have apparently no practical importance. They may be taken as constant at all pressures.

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* See paper by the author, in "Proceedings of American Association for Advancement of Science," St. Louis meeting, 1878.

Even these figures are probably higher than those sometimes reached with old journals which have been kept in good order many months or years, and which have worn to that remarkable mirror-like smoothness which is familiar to every experienced mechanic. We have obtained on the "railroad machine" values for sperm, and even lard, as low as one-fourth of one per cent., at pressures of less than 500 pounds per square inch, while cylinder lubricants, applied to bearings heated to the temperature of steam at 100 pounds pressure, have given coëfficients as low as one-ninth of one per cent.

70. FRICTION WITH VARYING VELOCITY.—It is only recently that it has been found that a serious modification of the value of the coëfficient of friction may sometimes be produced by change of velocity. Experiments made by late investigators have shown that, for very low velocities, in the cases studied, the frictional resistance to sliding is comparatively small, that it gradually and somewhat rapidly increases to a maximum as the velocity of sliding augments, and then, at higher velocities diminishes again,

approximating apparently to a constant minimum value.*

In the year 1858, Mon. H. Bochet presented a paper to the French Academy of Sciences† on this subject, in which he states that he had found the coëfficient of friction between surfaces of iron to be variable, diminishing as velocity increased.

M. Bochet proposed what was equivalent to the following formula:

$$f = \frac{a + b\,c\,v}{1 + b\,v}$$

in which f is the coëfficient of friction, and a, b and c are constants; v is the velocity of sliding in meters (or the velocity in feet divided by 3.28) per second. The value of these constants were (no lubrication):

a = 0.3 to 0.2 for dry and 0.14 for moist surfaces.
b = 0.03 for wheels and 0 07 for skids on rails.
c = undetermined, but taken as negligable.

Prof. Kimball, in 1876,* determined the following table of coëfficients for pine sliding on pine, and deduced the conclusions:

(1.) At a given inclination, the friction decreases with increasing velocity, at first rapidly, then more slowly.

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* Professor A. S. Kimball was the first to exbibit those facts with satisfactory completeness. Playfair had previously questioned the generally accepted theory.
† See "Compte's Rendus," April 26, 1858. ‡ "American Journal of Science," 1876.

(2.) At the same velocity the friction is greater the greater the angle of the sliding plane.

(3.) The value of the coëfficient tends to become constant.

(4.) The value of this constant seemed to be the same for all experiments.

COËFFICIENTS OF FRICTION.—PINE ON PINE.—KIMBALL.

Pressure, 1⅔ pounds per square inch.

Veloc. Ft. per Sec.	Values of Coëfficient.			
	1	2	3	4
4	0.260	0.273		
10	0.252	0.261	0.270	0.280
20	0.243	0.248	0.254	0.260
30	0.237	0.242	0.256	0.250
40	0.233	0.236	0.240	0.242
50	0.230	0.232	0.235	0.236
60	0.228	0.230	0.231	0.232
80	0.224	0.226	0.226	0.225
100	0.222	0.223	0.221	0.222
120	..	0 220	0.217	..

At pressures double and five times the above, the law still held.

Later experiments* gave the following:

PINE ON PINE. PRESSURE, 4 LBS. PER INCH.

Velocity inches per min.	Coëfficient of Friction.
5	0.19
11	0.21
75	0.24
100	0.25

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* "American Journal of Science," 1876.

LEATHER ON PINE. PRESSURE, 4 LBS. PER SQUARE INCH.

Velocity inches per min.	Coëfficient of Friction.
0.79	0.22
1.58	0.27
3.94	0.33
9.98	0.36
29.14	0.38
72.50	0.41
157.50	0.43
226.80	0.45
300.00	0.46
466.00	0.475

LEATHER BELTS ON CAST IRON PULLEYS.—KIMBALL.

V. in inches per minute.	T_2 lbs.	T_1 lbs.	C
0.37	30	13	0.41
0.52	30	12½	0.44
1.1	30	11½	0.48
2.3	30	10½	0.53
4.4	30	9½	0.58
15.4	30	6½	0.78
34.1	30	5½	0.86
80.3	30	4½	0.96
228.8	30	4¼	1.50

SAME—REPEATED AT HIGHER SPEEDS.

18	..	..	0.82
92	..	..	0.93
660	..	..	1.00
1190	..	..	0.96
1980	..	..	0.82
2669	..	..	0.69

The values of C are relative, and are not the absolute values of the coëfficients of friction. With a wrought-iron shaft turning in cast-iron bearings, well oiled, and a load of 66⅔ lbs. per square inch, at velocities of rubbing of 72, 272, 605, and 1,320 inches per minutes, the frictional resistance varied as 1, 0.60, 0.40 and 0.29; at the very low speeds of 0.007, 0.027, 0.060 and 0.132 inches per minute the relative resistances were as 0.37, 0.51, 0.73 and 1.00.

Professors Jenkins and Ewing,* experimenting at still lower velocities—0.0002 to 0.01 foot per second—with various metals and without lubrication, found a similar law to prevail.

Lubricated surfaces did not exhibit such a variation.

These experimenters suggest a probability that there exists a continuity of values between the gradually varying coëfficients for decreasing velocities and those obtained for statical friction.

Still later experiments, reported by Kimball,† on journals running with lubrication under pressure of 15 to 25 pounds per square inch, gave the following:

Velocity in Ft. per min....	1	3	5	7	10	15
Coëfficients..............	0.150	0.122	0.114	0.093	0.079	0 066
Velocity in Ft. per min....	20	30	40	60	80	100
Coëfficients..............	0.058	0.054	0.053	0.052	0.051	0.050

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* "Proceedings of Royal Society," 1876.

† "American Journal of Science," March, 1878, p. 194.

71.—COËFFICIENTS OF FRICTION.—THURSTON.

NEW JOURNAL OF STEEL; BEARINGS OF BRONZE; VELOCITY, PRESSURE AND TEMPERATURE, VARIABLE.
Lubricant: Standard Sperm Oil.

Speed per Min.	30 ft. per min.					100 ft. per min.					250 ft. per min.		500 ft. per min.		1,200 ft. per min.		
Press. per Sq. In.	200	150	100	50	4	200	150	100	50	4	200	100	200	100	200	150	100
Temp. Fah.																	
150	.0500	.0500	.0250	.0125	.125	.0140	.0074	.0025	.0037	.0630	.0047	.0028	.0053	.0037	.0060	.0058	.0061
140	.0250	.0330	.0110	.0087	.125	.0100	.0050	.0025	.0037	.0630	.0047	.0030	.0053	.0037	.0062	.0058	.0070
130	.0160	.0200	.0044	.0075	.125	.0087	.0041	.0019	.0037	.0630	.0047	.0030	.0053	.0037	.0065	.0062	.0075
120	.0110	.0110	.0044	.0075	.125	.0056	.0035	.0019	.0037	.0630	.0047	.0037	.0056	.0037	.0069	.0067	.0080
110	.0100	.0033	.0037	.0062	.094	.0044	.0033	.0019	.0037	.0630	.0050	.0044	.0062	.0050	.0075	.0075	.0087
100	.0075	.0028	.0031	.0056	.094	.0040	.0033	.0019	.0037	.0630	.0056	.0045	.0065	.0061	.0081	.0083	.0094
90	.0056	.0025	.0031	.0037	.094	.0040	.0033	.0019	.0037	.0630	.0070	.0052	.0075	.0061	.0100	.0170	.0150

Professor Kimball* gives the following table, showing a slight diminution of the coëfficient of friction with an increase of speed within a very low and limited range:

COËFFICIENT OF FRICTION.—KIMBALL.

Lbs. per sq. in.	*f* at Veloc. of 0.59 ft. pr. min.		*f* at Veloc. of 2.17 ft. per min.	
23.5	0.154	0.159	0.136	0.130
50.1	0.149	0.147	0.119	0.124
103.3	0.155	0 150	0.111	0.127
156.5	0.147	0.147	0.113	0.124
196.4	0.144	0.145	0.111	0.125

FRICTION WITH VARYING VELOCITY—THURSTON.—Referring to the table on page 185, in which the effects of varying velocities, as well as of coincident variation of pressure and of temperature, are exhibited as given by experiment in the Mechanical Laboratory of the Stevens Institute of Technology, it is readily seen that the change in value of the coëfficient of friction with change of velocity is not great for machinery in which that velocity remains within usual limits, and at the usual temperature of a cool and properly working journal. The effect of change of velocity varies, as is here shown, with change of temperature and of pressure.

For cool journals in good condition, lubricated with good sperm oil, and between the limits of 100 and 1,200 feet per minute, these values may be taken as varying approximately as the fifth root of the speed of rubbing, *i. e.*:

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* "American Journal of Science," March, 1878.

$$f = a\sqrt[5]{V}.$$

At a constant pressure of, say, 200 pounds, we may call $a = 0.0015$.

72. FRICTION WITH PRESSURE AND VELOCITY VARYING SIMULTANEOUSLY.—We may now readily construct an equation which shall give values of the coëfficient of friction for good journals, lubricated with sperm oil and for all ordinary variations, both of pressure and velocity; since

$$f \propto \sqrt[5]{V} \text{ and } f \propto \frac{1}{\sqrt{P}}, \text{ we have}$$

$$f = a\frac{\sqrt[5]{V}}{\sqrt{P}}.$$

in which we may take $a = 0.02$ to 0.03 for general use.*

The value of a for other conditions and with other materials may be determined by a comparison by means of the testing-machine of those materials under the assumed conditions with the results obtained with the standard oil, under standard conditions as here given.

73. FRICTION WITH VARYING PRESSURES, SPEEDS AND TEMPERATURES.—We have here some exceedingly interesting data. The following

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* *Vide* Paper by the author, "On Friction Measurement," etc., "Proc. Am. Assoc. for Advancement of Science," 1878.

were obtained by heating the bearing by its own friction to a maximum 170° Fahr. well within that liable to produce alterations of the oil, and noting the friction at successives temperatures while cooling. It should be remembered that no temperature readings can be taken as more than approximate.

FRICTION AND TEMPERATURE.—THURSTON.

Steel Journals, Lubricant, Sperm Oil. Velocity, 30 feet per minute.

Pressure lbs. per square in.	Temperature, Fahr.	Coëfficient of Friction : *f*.
200	150	0.0500
200	140	0.0250
200	130	0.0160
200	120	0.0110
200	110	0.0100
200	100	0.0075
200	95	0.0060
200	90	0.0056
150	110	0.0035
100	110	0.0025
50	110	0.0035
4	110	0.0500
200	90	0.0040
150	90	0.0025
100	90	0.0025
50	90	0.0035
4	90	0.0400

The figures just given would indicate that the sperm oil used in this instance and under these conditions, including that of exceptionally low speed, works best at lowest temperatures, and that a heating journal gives rapidly increasing friction and rapidly increasing danger. At usual temperatures—90° to 110° F.—the best pressure seems to have been from 100 to 150 pounds on the square inch.

It would, however, be wrong to predicate *general* conclusions on such limited data, and the study of the last table is exceedingly interesting and instructive.

There are there given coëfficients of friction for temperatures from 90° F. to 150°, for pressures up to 200 pounds per square inch, and for velocities of rubbing up to 1,200 feet per minute. This table is, in fact, a compendium of data for all ordinary conditions of the working of light and of moderately heavy machinery.

We find here some exceedingly valuable and very curious facts bearing directly upon our everyday work.

We have seen that at the low speed of thirty feet per minute, the coëfficient increases rapidly with increase of temperature, and that, at 200 pounds pressure, an increase of 50° F. may increase its value to nearly ten times the minimum, the rate of increase rapidly rising as pressures are greater.

We now find,* at speeds of 100 feet per minute, that the friction does not vary between 90° and 150°, at pressures below 50 pounds per square inch; but that it rises nearly 300 per cent. at a pressure cf 200 pounds, over 100 per cent. at 150 pounds, and 33 per cent. at 100.

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* These qualifying conditions were first stated in a paper by the author, read before the Amer. Inst. Mining Engineers, Oct., 1878. See "Proc. A. I. M. E." and "Jour. Franklin Inst.," November, 1878.

At speeds exceeding 100 feet per minute, heating the journal within this range of temperature *decreases* the resistance due to friction, rapidly at first; then slowly and gradually a temperature is approached at which increase takes place and progresses at a rapidly accelerating rate, It is seen that this change of law takes place at a temperature of 120° F. and upward; at all higher speeds the decrease continues until temperatures are attained exceeding those usually permitted in machinery and very commonly not far from 150°F., and sometimes up to 180° F. or probably even higher. I have found the decrease at 1,200 feet per minute to continue up to 175° F., at which the value, at 200 pounds pressure, was, in the cases determined, 0.0050. The limit of decrease is reached under 100 pounds pressure, at 150° F., when running at this high speed.

At 200 pounds pressure, the *temperature of minimum friction* for conditions here illustrated seems to be, in Fahrenheit degrees, about

$$t = 15\sqrt[3]{V}.$$

On either side this point on the thermometric scalc it may be assumed, for a narrow range, to vary as the temperature departs from that point, directly or inversely, as the case may be, as the temperature. The fact is, however, that this coëfficient of minimum friction is found usually over quite a wide range of temperature.

Again, studying in this most instructive of our tables, the method of variation with pressure at higher temperatures, we find the effect of change of pressure to be much more marked at the higher temperatures at low speeds, and, singularly enough, we note, as when studying the effect of variations of friction with change of temperature at a standard pressure as affected by variation of speed, we here find a change of law for the higher speeds.

At a velocity of 1,200 feet per minute, the coëfficient remains practically uniform with varying pressure at 150 F., while below that temperature the friction coëfficient diminishes with increasing pressure. At velocities of rubbing of 250 to 500 feet per minute, the temperature of the constant coëfficient is about 100° at 100 feet this peculiar condition is seen at about 120°, when *extreme* pressures (4 pounds and 200) are compared, but the value is seen to be a little over one-half as much at 50 and 150 pounds, and to become a mimimum—0.0019—at 100 pounds pressure; a similar behavior is noted at the lowest speed observed—30 feet—

at about 125° F., and the same fall to a minimum at the intermediate pressure.

It would seem that at all times there is a tendency to an acceleration of outflow from the journal, with increasing of fluidity due to increasing temperature, which tends to cause an increase of friction, while the effort of capillarity to resist this outflow seems effectively aided by increasing the velocity of rubbing.

A *balance* between these opposite influences is seen to take place at the slowest speed when the pressure is somewhere below 4 pounds per sqnare inch; this occurs at a speed of 100 feet per minute at a pressure of 50 pounds, at 250 feet, when the pressure becomes about 150 pounds probably; it happens at a speed of 500 at somewhere about the same point, and at 1,200 feet per minute the benefit of increased speed is sufficient to produce this balance when the pressure exceeds 200 pounds per square inch.

These data would seem to give very useful information relative to the method of action of lubricating materials.

Finally—it has now become evident that such a series of comparisons as I have here made are needed in every case in which the real value and the extent and the conditions of application of any single oil or other unguent are to be learned. Such a systematic examination reveals precisely the conditions which the lubricant best meets, and tells with certainty at what pressure and at what speed it does its best work.

Conversely, the speed, the pressure, and other conditions of working being known, a reference to a set of such determinations for various lubricants being made, it is easy to ascertain at once which is best adapted to the work in view.

Thus, having had occasion to determine the value of the friction coëfficient of a material having a very high reputation as a "cylinder oil"—*i.e.* an oil for use in the cylinders of steam engines—it was found that its distinguishing peculiarity, as compared with oils not specially adapted for such purpose, was a continually diminishing coëfficient quite up to the limits of temperature of locomotive steam pressure.

Any new lubricant should always have its true value and best adaptations thus determined. I have presented the figures for a fine steel journal running in good bronze bearings, and lubricated with sperm oil, not simply as an illustration, but principally as representative of the best set of conditions for use as a *standard* in making comparisons of other unguents of less value or less known, or under less favorable conditions.

74. ENDURANCE OR WEARING POWER OF LUBRICANTS.—The difficulties to be encountered

in attempts to determine, with even approximate accuracy, the wearing power of lubricating materials have already been referred to; but only experience can enable any one to fully realize the patience and care demanded in the effort to secure reliable data.

The obstacles which are to be met with in the attempt to make practically useful application of the facts acquired are hardly less serious and will be stated in detail after describing the results of experiments which have already been made. These researches have been continued, and it is hoped that other and yet more valuable results may hereafter be obtained.

Testing a large number of the oils* of commerce for durability on a cast-iron journal, we at one time used 32 milligrammes at each application and noted the *time required to run the journal dry*, with this result:

OILS OF COMMERCE, AVERAGE ENDURANCE.—THURSTON.

Pressure per square inch.	Running Time.			Rise of Temp, b.	Ave. coefficient f.	Heat coefficient $100\frac{a}{b}=C$.
	Ave. a.	Min.	Max.			
8 lbs.	82	17	411	167° F.	0.20	50.
16 "	29	9	97	212	0.16	14.
32 "	10	2	19	228	0.12	5.
48 "	8	1	13	228	0.10	4.

The "heat coëfficient" is a valuable datum, as exhibiting the relative increase of temperature per minute during the trial, Its value is sometimes— wrongly, although in some cases nearly correct—taken as a measure of endurance.

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* This collection included many oils of little value as lubricants.

Several well-known oils ran thus—the speed being 750 ft. per minute.

ENDURANCE, ETC., OF LUBRICANTS ON CAST-IRON.*—THURSTON.

Name.	Lbs.	Running Time.	Rise of Tem.	Co-eff. *f*.	Heat co-eff. *c*.
Summer Sperm......	8	111 min.	230° F.	0.13	48.2
" "	16	29	225	0.10	12.8
" "	48	9	195	0.08	4.6
Lard...............	8	165	270	0.13	61.1
"	16	33	215	0.11	15.3
"	48	7	265	0.10	2.6
Olive..............	8	83	170	0.13	48.8
"	16	41	245	0.10	16.7
"	48	14	240	0.06	5.8
Cotton Seed........	8	107	185	0.16	57.8
" "	16	45	275	0.12	16.3
" "	48	12	310	0.07	3.9
Cod................	8	40	200	0.15	20.0
"	16	14	175	0.12	8.0
"	48	9	220	0.07	4.1
Crude mineral (?)....	8	129	105	0.10	122.0
" "	16	97	285	0.10	34.0
" "	48	5	270	0.10	1.8

Comparing a mixture or plumbago and grease with sperm oil, the former was found to have a lower coëfficient, to heat up less rapidly and to endure several times as long. It was also indicated that plumbago in very fine flakes was better than in an impalpable powder—a result which was to me quite unexpected.†

Testing for durability, on a small steel journal, sperm and lard oils gave these results:

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* See "Polytechnic Review," March 3, 1877.

† See "American Machinist," November, 1873, p. 3.

ENDURANCE OF SPERM AND LARD OILS.—THURSTON.
Durability of one 8-milligramme drop: Feet Run.

Pressure per sq. inch.	100	200	250	275
Sperm..................	7204	7685	7675	7521
Lard.....................	6797	7139	7090	7008

Others of the commercial oils found in the market and largely purchased by consumers, who have no means of testing them, endure but for a very small fraction of the time and the distance traveled with sperm and lard, and I have never yet found an oil which equals sperm in this quality.

The "Railroad Machine" has given the following for sperm and lard oils, using a much larger quantity,

	300 lbs.	500 lbs.
Sperm, raw, (ft.)	19,800	13,500
Lard, " "	10,557	7,515

The coëfficients being,

Sperm,	0.0046	0.0033
Lard,	0.0059	0.0044

The journal was in this case of very soft steel, 3¼ inches in diameter and seven inches long, and was driven at a speed corresponding to 30 miles an hour on the track.

In the attempt to make use of such determinations of the endurance of lubricants in daily practice, the investigators meet with a serious difficulty which has no relation to the character of the material used. It is an important fact, and one which should be constantly borne in mind, that the maximum wearing power of a lubricant, as we have here defined and determined it, has no necessarily definite relation to the quantity which will be actually used, or even required, when working under other conditions.

Usually the same amount will be used, whether it be of great or of little wearing power, the amount being usually determined by the method of feeding more than by its intrinsic character. Other things being equal, the more viscous will feed more slowly, and will, therefore, be apparently of higher wearing power than the more fluid lubricant; a grease will last longer than an oil; the method of applying the lubricant to the journal will determine whether it is economically or wastefully used. These last are vastly more important facts than they are generally supposed to be; regular trains on railroads have been known to use *nine times as much** grease as an experimental train on which the most rigid economy was exercised.

It thus becomes evident that the proper method of procedure is to first determine the value of the lubricant by a series of careful tests at the pressures, velocities and temperatures, and with the kind of rubbing surfaces proposed to be used, *then* to find and adopt that method of feeding which will insure maximum economy. As a rule, however, determinations of endurance are of comparatively little value in every day practice, because their use is rarely, and seldom can be, regulated by their endurance; the same amount would generally be used and the same quantity wasted, whether the wearing quality be high or low. The real value of a lubricant is, therefore, generally measured by its power of reducing friction, as I have already remarked.

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* "Railroad Gazette," Sept. 20, 1878.

The following are the details of a trial reported at the Brooklyn Navy Yard, in which the less certain but less troublesome method was adopted:

The oil was measured by dropping. The same quantity, five (5) drops, was used in all the tests.

When a seeming discrepancy appeared, or doubt arose regarding any result, the experiment was repeated until satisfaction was obtained.

The driving power came from the Navy Yard engine, and the speed of the testing machine varied with the work done by the engine. Owing to this cause it was not claimed that the results were absolutely correct. The average speed was, however, taken, which so nearly approximates uniformity, that the data may be considered correct for all practical purposes of comparison. Two series of tests were made, one of three (3) minutes runs, and another of (1) minute each.

OILSs	ONE MINUTE RUNS.				THREE MINUTE RUNS.				
	Revolutions.	Increase of heat in units of degrees Fahrenheit.	Coëfficient *c*.	Comparative efficiency, sperm being 100.	Total Revolutions.	Per Minute.	Increase of heat in units of degrees Fahrenheit.	Coëfficient *f*.	Comparative efficiency, sperm being 100.
	a	b	$\frac{a}{b}=c$	h	d	a'	e	$\frac{d}{e}=f$	h'
Sperm..........	1812	43.5	41.6	100	5506	1835.3	82	67.1	100
Prime Lard.....	1790	46	38.8	93.2	5741	1913.6	90	63.8	95.1
Lard No. 1......	1883	50	37.6	90.5	5428	1807	90	60.3	89.8
Lard No. 2......	1810	50	36.2	87.02	5500	1833	96	57.3	85.4

Columns b and e give the increase of heat in degrees (Fahrenheit) of the journal, starting from a nearly constant temperature of 78° or 80°. The unit of comparison is the number of revolutions obtained for each degree of increase in temperature, and is obtained in the minute runs, by dividing column a by column b which gives the coëfficient column c $\left(\frac{a}{b} = c\right)$ and in three (3) minutes runs by dividing column d by e, giving the coëfficient in column f $\left(\frac{d}{e} = f\right)$

Columns h and h' compare the efficiency on the basis of sperm being 100.

It need hardly be repeated here that the ratio of heat developed to revolutions made or distance traversed has no necessary and definite relation to the real power of endurance of the oil.

75. COMMERCIAL VALUE OF LUBRICANTS. The real value of a lubricant to the user is a somewhat difficult quantity to determine, since it really depends, not upon the relative friction-reducing power and endurance, as usually assumed, but upon the value of the power saved by its use. This value varies in every case, and is affected by every variation of working conditions.

The market value is determined, as in all commercial operations, by that law of supply and demand which, usually, if sufficient time is allowed for its operation, brings prices into a correct relative order, but not necessarily into a true proportion of values. It is generally the fact that "the best is the cheapest" to the consumer, and this rule is probably almost always applicable in the purchase and use of lubricants. It is frequently the fact that the consumer can better afford to use the highest priced article than to take those of lower value as a gift.

An approximate value by which to compare the oils, can be calculated, based on the assumption that they will have a money-value proportionate to their durability and to the *inverse* ratio of the value of the coëfficient of friction. Thus: suppose two oils to run, one 10 minutes and the other 5, under a pressure of one hundred pounds per square inch, and both at the same speed, and suppose them to give on test for friction the coefficients 0.10 and 0.06 respectively.

Their relative values might be taken at $\frac{10}{10} = 1$ and $\frac{5}{6} = 0.833$. If the first is worth one dollar, the second should be worth 83$\frac{1}{3}$ cents.

In many cases, however, about the same quantity would be applied by the oiler whatever oil might be used, and their values to the consumer would be in the inverse proportion of the values of their coëfficients of friction, *i. e.*, as 6 in the above case is to ten, thus making the value of the second \$1.66⅔, and showing that it would be better to use the latter at anything less than this price than the first at one dollar.

I have been accustomed to use these methods of comparison in reporting upon the values of lubricants sent in for test simply because they are generally considered to be correct by dealers and users, and because there has been no better method suggested of assigning an approximate figure for market price.

The real difference in values of any lubricants to any user may, nevertheless, be determined in any given case when the cost of power is exactly known and when the quantity of the several unguents required to do the same work has been found, and their several coëfficients of friction given.

The difference in actual value to the user where any two unguents are compared is measured by the cost of the difference in the amount of power expended in driving the machinery, when lubricated first with the one and then with the other of the two materials.

As power is usually much more expensive when developed in small than when demanded in large amounts, the economy to be secured by adopting a good lubricant is the greater as the magnitude of the work is less. In large mills and wherever work is done on a very large scale, the cost per horse-power and per annum may be taken roughly at about $50 a year, while for small powers this figure is doubled or even trebled and quadrupled.

Every reduction of power to the extent of one horse-power by the introduction of an improved material or system of lubrication thus effects a saving of $50 a year and upward; the difference between this amount and the extra cost of the new kind of lubricant represents the annual profit made by the change.

Should it happen, as is sometimes the fact, that the better unguent is also the cheaper, an additional profit is made which is measured by that saving in cost.

In an ordinary small mill or in a machine-shop in which one hundred horse-power is used, a change in lubricant will often effect an average saving of five horse-power, and a consequent economy of, probably, $500 a year. The total amount of oil used in such a case might exceed 100 gallons, but may sometimes be as little as 40 gallons.

The consumer could, in such a case, better afford to pay $5, or perhaps even $12.50 per gallon for the good oil than accept the less valuable lubricant as a gift.

Mr. J. E. Denton has taken the trouble to apply these principles to a common case in railroad economy, thus:

Let Q equal quantity used of one lubricant, in gallons;
Q' “ quantity used of another lubricant, in gallons;
p “ actual cost of the one oil, per gallon;
p' “ allowable cost of the second oil, per gallon;
R “ distance traveled, per gallon;
R' “ “ “ “
F “ fuel used on the train with the first oil;
F' “ fuel used on the train with the second oil;
c “ cost of fuel;
f & f' “ the coëfficients of friction;
r “ ratio of total resistance of train to that of axle friction.

Using the one oil, the expense would be

$$Qp + \frac{cF}{r};$$

with the second it would be

$$\frac{R}{R'}Qp' + \frac{f'}{f}rcF.$$

Then

$$Qp + rcF = \frac{R}{R'}Qp' + \frac{f'}{f}rcF,$$

and

$$p' = \frac{Qp + rcF - \frac{f'}{f} rcF}{\frac{R'}{R} Q}.$$

Making m and m' the values per gallon per train mile,

$$p : p' :: m : m', \text{ and } m' = \frac{mp'}{p}.$$

Pure lard oil could best be taken as a standard for comparison on railroads.

The experiment was recently tried on one of the great railroads of this country of using pure lard oil in summer and the best of sperm oil in winter on freight trains, employing a man to attend simply to lubrication. The effect was to increase the number of cars which could be hauled by each engine about ten per cent. and to secure much greater regularity of service. The saving effected in cost of transportation was sufficient to pay double the total cost of oil used and labor employed.

In another case in which fifty per cent. more was paid for one oil than for another, the higher priced oil was found much the cheaper on the score of saving the expense of hot journals alone.*

76. USE OF THE FIGURES GIVEN.—There are three kinds of calculations which the engineer

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* "Railway World," 1875.

is called upon to make, in which these figures are needed:

1. It is required to know what effort is needed to start a heavy body into motion when resting upon a smooth surface.

2. It is required to know what force will keep a body in motion when once started.

3. It is necessary to ascertain how many horse-power, or what fraction of a horse-power, will be wasted by friction under known conditions.

To determine the force required to start in the first case we simply multiply the total weight or pressure which holds the rubbing surfaces in contact by the proper coëfficient of friction, as given in the tables representing that case. Thus, suppose a weight or pressure of 2,000 pounds to be exerted on surfaces having four square inches in contact, the total pressure is 2,000, the pressure per square inch is 500, and if sperm oil be used and the surfaces are of good metal, as in the last table of coëfficients, the coëfficient will be 0.15, or 15 per cent. The resistance to motion will be, therefore, 2,000 × 0.15 = 300 pounds.

In the second case, adopting the same conditions except that we wish to obtain the resistance while in motion, we find the coëfficient to be 0.004, or four-tenths of one per cent. The resistance due to friction, while actually moving, is therefore 2,000 × 0.004 = 8 pounds.

In the last case, we determine first the “work” wasted in friction, then the horse-power.

To obtain the “work”—the term being used in the scientific sense, and being therefore taken as the product of the resistance into the distance through which that resistance is overcome, or in “foot pounds,” as usually measured—we may use a set of rules which I will give in the same order and nearly the same terms that are adopted by Clark,* in which

P	equals	the load or pressure (total) in pounds;
f	“	the coëfficient of friction;
s	“	space rubbed over in feet;
t	“	time in minutes;
v	“	velocity of rubbing in feet, per minute;
R	“	revolutions per minute;
U	“	work in foot pounds;
$H.P.$	“	horse-power;
d	“	diameter of journal in inches;
r	“	radius “ “
l	“	length “ “

WORK LOST IN FRICTION.

1. Flat surfaces, $U = fPs$.
2. Cylindrical journal per revolution $= 0.26fPd$.
3. “ pivot (end) “ $= 0.175fPd$.

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* “Manual of Rules, Tables and Data,” etc.

HORSE-POWER WASTED IN FRICTION.

1. Flat surfaces, $H.P. = \frac{fPv}{33,000}$.

2. Cylindrical journal $= \frac{fPRd}{127,000}$.

3. " pivot $= \frac{fPRd}{189,000}$.

77. CONCLUSIONS.*—Studying the facts here laid out and the data acquired by many hundreds of other experiments made on one or the other of these last-described machines for testing lubricants, we may now recapitulate the facts and figures for ordinary use in machine-design and in estimating losses of power by friction.

(1.) The great cause of variation with well cared-for journals is alteration of pressure, and it is seen that the higher pressures, within the range of these experiments, give the lowest percentages of loss of power by friction.

(2,) The value of the coëfficient is seen to be greatly modified by the state of the rubbing surfaces; and the necessity of keeping journals in perfect order cannot be too strongly insisted upon. A single scratch has its effect in wasting power. A journal should have its surface as smooth and as absolutely uniform as a mirror, Every well-kept journal has such a surface;

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* See "Trans-Am. Inst. Mining Engineer; 1878, Journal Frankiln Institute," Nov., 1878.

(3.) For general purposes, the value of the coëfficient may be obtained pretty closely by the square-root of the pressure per square inch by 0.08 to 0.10, *i. e.*: $f = \frac{0.10}{\sqrt{p}}$, in which case it is given as that fraction of the total pressure which measures the resistance due to friction.

(4.) The coëfficient for rest or starting may similarly be taken as about 0.02 the cube-root of the pressure—*i. e.*, $f' = 0.02 \sqrt[3]{p}$ for sperm and for crude mineral oil of good body, and 0.015 the cube-root—$f' = 0.015 \sqrt[3]{p}$—for lard oil. For closer estimates, the tables just given can be referred to directly. It would seem that each material has its own coëfficient and its own appropriate exponent in the expression $f = c P^{\infty}$.

(5.) The coëfficient for the instant of coming to rest, under conditions such as are here given, is nearly constant, and may be taken at 0.03.

(6.) The resistance due to friction varies with velocity, decreasing with increasing velocity rapidly at very low speeds, as from 1 to 10 feet per second, and slowly as higher speeds are reached, until the law changes and increase at ordinary temperatures takes place, and at a very low rate throughout the whole range of usual velocities of rubbing in machinery.

The value may be taken, at a pressure of 200 pounds per inch, as $f = 0.0015 \sqrt[5]{V}$.

(7.) With pressure and velocity varying, we may take roughly,

$$f = 0.02 \frac{\sqrt[5]{V}}{\sqrt{P}} \text{ to } f = 0.03 \frac{\sqrt[5]{V}}{\sqrt{P}}.$$

(8.) The effect of heating journals under conditions here illustrated is, to *increase* the friction in proportion to the square of the increase of heat above say 90° to 100° F., at a speed as low as 30 to 100 feet per minute, while at higher speeds the opposite effect is produced, and the coëfficient *decreases* more nearly as the square root of the rise of temperature.

Under all conditions commonly met with by the maker of machines, the latter is the method of change,

(9.) The temperature of minimum friction, under the conditions of these experiments, is about $t = 15 \sqrt[2]{V}$ for a pressure of about 200 pounds per square inch.

(10.) The endurance of any lubricant should be determined by actually wearing it out upon a good journal under the pressures and velocities proposed for its use.

The economy with which it can be used will also be dependent upon its natural method and rate of flow, and upon its capillary qualities, as well as upon its intrinsic wearing power, and the method adopted in feeding it. Greases, therefore, are usually more economical than oils, even if having less wearing capacity.

(11.) The only method of learning the true value of a lubricant, and its applicability in the arts, is to place it under test, determining its friction-reducing power, and its other valuable qualities, not only at a standard pressure and velocity, and at ordinary temperatures, but measuring its friction and endurance as affected by changing temperatures, speeds and pressures throughout the whole range of usual practice.

(12.) The true value of an oil to the consumer is not proportional simply to its friction-reducing power and endurance under the conditions of his work; but its value to him is measured by the difference in value of power expended, using different lubricants, less the difference in total cost of oil or grease used ; but for commercial purposes no better method of grading prices seems practicable than that here adopted, which makes their market value proportional to their endurance, divided by their coëfficients of friction.

The consumer will usually find it economical to use that lubricant which is shown to be the best for his special case, without regard to price, and will often find real economy in using the better material sufficient to repay excess in the total cost very many times over. He cannot afford to accept low grade unguents, even without charge.

(13.) To secure maximum economy, the journal should be subjected to a pressure determinable by either Rankine's or Thurston's formula (Art. 28); the most efficient materials should be chosen for the rubbing surfaces; they should be reduced to the most perfect state of smoothness and perfection in form and fit; a lubricant should be chosen which is best adapted for use under the precise conditions assumed; the lubricant should be supplied precisely as needed, and by a method perfectly adapted to the special unguent chosen.

The semi-fluid lubricants, if equally good reducers of friction, are usually the most economical, in consequence of their peculiar self-regulating flow, as the rubbing parts warm or cool while working.

Where heating is not to be anticipated, maximum economy is obtained by the minimum rate of supply allowable only if that supply be maintained with absolute uniformity.

INDEX.

PAGE.
Abrading Friction 20, 26, 218
Abrasion Limit 27
  of Steel 28
Acids (*see* Chemical).
  Detection of, in Oils 64
  Rise of Temperature by addition of 79, 80
  Tests with 79–111
Adhesion of Belts (*see* Belts, Ropes, Wire Testing).
  Locomotive Driving Wheels 29, 32
  Wire Rope on Guttapercha 36
Adulteration (*see* Acids, Chemicals, Tests, Testing).
  Oils 62, 64, 80
Air, Resistance on Railroads 15
Almond Oil, Action of Acids 76, 79, 95, 97, 104
  Density 69
Sweet Oil, Analysis of 61
Ammonia 93
Amonton's Experiments 24
Analysis, General Methods of 90
Angle of Friction 25, 26
  Repose 25, 27
Animal Oils, Action of Acids 79, 89, 90, 95
  Density 69
  Durability 151
  Effect of Chlorine upon 89
  Effect of Various Reagents 95
  Rise in Temperature by Friction 151
  Analyses of Chevreul & Braconnet 61
Anti-friction Metals 47
Apparatus for Measuring Friction, Morin 1
  for Testing Lubricants, Ashcroft 112
    Bailey & Co 119
    Brooklyn Navy Yard 115
    Crossley 117
    Ingham and Stapfer 115
    Lake Shore & Michigan Southern R. R 115, 117
    McNaught 116
    Napier 116
    Thurston 128, 145
Arts, Society of, Experiments on Resistance of Omnibuses 12
Asbestos as a Lubricant
Ashcroft, Machine for Testing Lubricants 116
Asphalt as a Lubricant 38
  Roads 12
Axles (*see* Coëfficient, Friction, etc).
  Car, Friction of Journals 13
  Wood's Experiments on Friction of 39
Babbitt Metal 47

- **Bailey & Co.,** Apparatus for Determining Rate of Gumming and Viscosity of Oils 88
  - Fire Test Apparatus 76
  - Machine for Testing Lubricants 115
- **Bank** (Cod) **Oil,** Density 69
  - Action of Acids 79, 95
- **Bayberry Wax in Lubricant Mixtures** 51
- **Bearings** (*see* Boxes, Iron, Steel).
  - Anti-friction Linings 47
  - Lead Linings 47
  - Girard's Palier-glissant 47
  - Shaw's Water-bearings 88
  - Surface, Relation to Friction 9, 10
  - White Metal 39
- **Beech Oil,** Action of Acids 79, 95–104
  - Density 69
- **Belts,** Friction of 18, 34–37
  - India Rubber, Adhesion and Strength 37
  - Leather on Cast Iron
  - Tension on 34–37
- **Benzine,** Density 70
- **Bichloride of Tin.** Use in Tests 91, 93, 98, 99, 108, 110
- **Bisulphide of Calcium,** Use in Tests 91, 92, 95, 105. 107, 108, 109
- **Bleached,** Deodorized, Lubricating Oil. Coëfficient of Friction 157
- **Boxes,** Cast Iron, Wrought Iron Journals, Friction 183
  - Bronze, Steel Journals, Friction 185–187
- **Braconnet & Chevreul,** Analyses of Fatty Substances 61
- **Brake-Blocks,** Friction of 32, 33
- **Brakes and Rails,** Friction of 29
- **Brick on Limestone,** Friction of 26
- **Briggs and Town,** Experiments on Belts 36
- **British Thermal Unit** 42
- **Bronze on Bronze,** Friction 38
  - Boxes, Steel Journals—Friction 185–187
- **Brooklyn Navy Yard,** Machine for Testing Lubricants 116
  - Tests 151–153
- **Burning Points of Oils** 45, 74, 76, 78
- **Calcium** (*see* Bisulphide)
- **Caloni,** French Thermal Unit 42
- **Camline Oil** Action of Acids 79, 95–104
  - Density 69
- **Car Axles** (*se.* Axles—Railroad).
  - Friction of Journals 13
- **Car Wheels,** Coning, Resistance due to 17
  - Loose, Resistances of 17
- **Carbonate of Lead** (*see* Lead, White).
- **Carriages,** Morin's Experiments 43
- **Castor Oil** 59
  - Action of Acids 79, 95–104
  - Cold-pressed—Coëfficient of Friction on 157
  - Endurance 153
  - Value as a Lubricant 127
- **Chateau's General Reactions** 91
- **Chanute,** Analysis of Railroad Resistances 17
  - Resistance due to Coning of Car Wheels 17
- **Characteristics of Unguents** 43
- **Chemical** (*see* Reaction, Reagent)
  - Methods, Composition of Oils 61
  - Tests of Oils 63, 64, 79–111

Chloride, Action of Acids.......... 79, 95
  of Zinc—Use in Tests.......... 91, 92, 95, 96, 106, 107, 110
  Density.......... 69
Chlorine, Effect upon Animal Oils.......... 89, 109
  Action of Acids.......... 79, 95
  Density.......... 69
  Effect upon Vegetable Oils.......... 89, 106
Chevreul & Braconnet, Analyses of Fatty Substances.......... 61
  de Saussure, Analyses of Fatty Substances.......... 61
Clark, Formula for Resistance of Vehicles.......... 13
  Formula for Work Lost in Friction..........
  Power Transmitted by Leather Belts..........
  Determinations of Friction of Mill Shafting.......... 40
Classification of Unguents.......... 61
Cloth, Friction of.......... 27
Cocoanut Oil, Coëfficient of Friction on Cast Iron Journals.......... 157
  Density.......... 69
Cod Oil, Action of Acids.......... 100 102
  Coëfficient of Friction.......... 195
  Density.......... 69
Cod Liver Oil, Action of Acids.......... 95-98, 103, 104
  Density.......... 69
Coefficient of Friction (*see* Friction Oils, Greases, Iron, Steel).
  with Varying Velocity.......... 181-187
  for Wheels.......... 182
  at Varying Velocities, Low Pressures and Slow Movements.......... 186
  Velocity, Pressure and Temperature Variable.......... 185, 187
  (rolling) for Wood.......... 10
  (rolling) for Metal.......... 10
  of Railroad Trains.......... 13
  on Roads.......... 16
  How Determined.......... 21
  of Standard Authorities.......... 26, 28
  for Shafting.......... 40
  Various Lubricants on Cast Iron Journals—Thurston.......... 156, 157
  of Rest or Starting.......... 28, 206, 209
  for General Purposes.......... 209
  of Motion.......... 26
  of Heat of Commercial Oils.......... 194-196
Cohesion Figures, Oleography.......... 81
Cold (*see* Congelation).
Coleman, Test of Oils by Addition of Acid.......... 80
  Experiments on Temperature of Spontaneous Combustion.......... 80
Colza Oil, Action of Acids.......... 95, 104
  Analysis of.......... 61
  Density.......... 69
  Durability.......... 151
  Rise in Temperature by Friction.......... 151
Combustion (*see* Fire-Test, Heat, Temperature, Flash, Flashing Burning Heat, Temperature).
  Spontaneous, Temperature of.......... 80
Commercial Value of Lubricants (*see* Value).
Composition, Alteration of.......... 62
  of Oils, Chemical Methods.......... 61
Congelation (*see* Fire-Test).......... 72
  of Oils.......... 78, 79, 153
  Point to Determine.......... 79
Coning of Car-Wheels, Resistance due to.......... 17

Copper, Acted upon by Oils.... 63
  on Oak, Friction.... 26
  and Lead, Detection of.... 63
  in Oils, Detection of.... 63
Cords (*see* Belts).
  Friction of.... 18
  Rigidity of.... 18
Cost of Lubricants (*see* Value).
Cotton Seed Oil, Action of Acids.... 95–104
  Coëfficient of Friction.... 157, 195
  Density.... 69
  Endurance on Cast Iron Journals.... 195
  Refining of.... 55
Coulomb, Experiments on Friction.... 24
  Law of Rolling Friction.... 97
Crank-Pins, Lubrication of.... 176
Crossley, Apparatus for Testing Lubricants.... 117
Curves, Railroad, Elevation of Outer Rail, Whinery.... 18
  Resistance of Railroad Trains on.... 16
Cylinder Lubricants.... 136, 138
  Oils, Action of Acids.... 79, 85
  Density.... 69
De Saussure & Chevreul, Analyses of Fatty Substances.... 61
Debaure, Resistance of Vehicles on Macadamized Roads.... 12
Densimeter.... 65
Density of Oils (*see* Specific Gravity).
  of Petroleum.... 70
Denton, Formula for Commercial Value of Lubricants.... 204, 205
Deodorized White Lubricating Oil, Coëfficient of Friction.... 157
Detection of Copper and Lead.... 63
Diagometer, Rousseau's.... 72
Distillation, Temperature of.... 72
Drying of Oils, Effects of Various Reagents.... 95
  of Oils, Tests.... 85
Dupuit, Resistance of Wagons on Macadamized Roads.... 12
Durability (*see* Endurance).
Duson Oil, Endurance.... 151
  Rise in Temperature by Friction.... 151
Earlier Researches.... 149
Economy, How Secured.... 212
Elaine Oil, Density.... 99
  Action of Acids.... 79, 95
Electric Conductivity of Oils.... 72
Elephant Oil, Friction.... 157
Endurance and Gumming.... 140, 193
  Commercial Oils at Different Pressures.... 194-196
  of Greases.... 197
  of Lard Oil.... 165, 170-173
  of Sperm Oil.... 165, 170-173
  Tests with Bailey's Apparatus.... 117
  Tests of Brooklyn Navy Yard.... 142, 198, 199
  Napoli's Experiments.... 151
  Test, Lake Shore & Michigan Southern Railroad.... 153
  Tests, Thurston's Method and Apparatus.... 141, 143
  Tests, U. S. Naval Engineers' Method.... 142
Engine Oil, Endurance.... 151
  Rise in Temperature by Friction.... 151
  Action of Acids.... 78, 95
  Density.... 69

Expansion, Coëfficient for Oils 68
Experiments, Amonton's 24
  Coulomb's 9
  Ewing & Jenkins' 184
  Morin's 16, 24
  Metcalfe's 125
  Thurston's 128–212
  Van Cleve's 155
Ewing & Jenkins, Experiments 184
Fats, Action of Acids 79, 95
  Density 69
Fatty Substances, Analyses of Chevreul & Braconnet and De Saussure 61
Feeding of Lubricants, Methods 198, 210, 212
Fehling, Tests of Oils by Addition of Acids 79, 80
Figures, Cohesion, Oleography 81
Fire-Tests (*see* Heat).
  for Oils 72
  ——Bailey 72
  Millspaugh 74
  Tagliabue 73
Fish Oils, Action of Acids 79, 95
  Density 69
  Action of Acids 95, 101
  Endurance of 152
  as Lubricants 49
  Lubricating Value of 152
Fixed Oils, Effect of Various Reagents 95
Flange Resistance on Railroads 15
Flashing Point of Oils 45, 74, 76, 78
Fluid Friction 9, 18, 19
Fluidity of Oils (*see* Viscosity).
  as Affecting Endurance 197
  of Lard Oil 89
  Rate of Flow through Orifices 89
French Thermal Unit 42
Friction (*see* Abrading, Axles, Belts, Brake, Coëfficient, Fluid, Greases, Iron, Journal, Oils, Pressure, Quiescence, Rolling, Ropes, Steel, Temperature, Velocity).
  Angle of 25, 26
  Authorities and Experiments 24
  Of Brakes and Rails 29, 30
  Of Cloth 27
  Of Cordage 18
  Defined 9
  Effects of 42
  Of Fibrous Materials 27
  On Cast Iron Journals—Thurston 156
  Horse Power Wasted by 208
  Of Ice 28
  Of Journals (*see* Journals) 18
  Of Locomotives 14
  Maximum of 190, 210
  Measurement of 20, 21, 25
  Of Motion 20, 26
  Of Mill Shafting 40, 46
  With Pressure and Velocity, Varying Simultaneously 187
  Of Pump Pistons and Press Plungers 35
  Resistance of Railroad Trains 13

  Sliding 20, 26
  Of Steel Skates 29
  With Varying Pressure 173
  With Varying Pressure, Speed and Temperature 187
  With Varying Velocity 180-184
  With Varying Velocity, Pressure and Speed 187
  Work Lost by 207, 208
Galipoli, Viscosity of Oils 85, 87
Galton and Westinghouse, Experiments on Pressure of Brake Blocks 33
  Experiments on Resistance of Skidded Wheels 33
Girard's Palier-glissant 48
Granite Macadamized Roads, Resistance of Omnibuses 12
  Paving, Resistance of Omnibuses 12
Graphite and Lard as a Lubricant 38, 52
Graveled Macadamized Roads, Resistance of Omnibuses 12
Gravity (*see* Specific) ....
Greases, Action of Acids 79, 95
  Coëfficient of Friction 177
  Density 69
  Different Compositions 50, 51
  Endurance of 197
  Friction of 177
  How Fed 59
  As a Lubricant 40
  Plumbago 195
  Value as a Lubricant 127
Gumming of Oils (*see* Viscosity).
  And Drying of Oils 85
  And Endurance 140
  Nasmyth Method of Test 85
  Tests 85
  Thurston's Tests 146
  Wheeldon Determinations 150
Gun Bronze, Bearings 39
Gutta-percha, Friction of Wire Ropes on 36
Heat (*see* Combustion, Fire Test, Temperature).
  Coëfficient of Commercial Oils 194-196
  Effect on Oils 72
  Effect on Unguents 72
  Prevented by Lubrication 42-44
  Units, British and French 42
Heating of Bearings, by Different Oils 150-155
  Of Journals, Prevention Mixtures 50, 51
Hempen Cord, Friction of 29
  Ropes, Rigidity of 18
Hempseed Oil, Action of Acids 95-104
  Density 69
Hicks' Value for Friction of Hydraulic Press Plungers 37
Hodgson's Machine, For Testing Lubricants 121-125
Hopkins' Lead Linings for Bearings 47
Horsefoot Oil, Action of Acids 95-104
  Density 69
Horse Power Wasted in Friction 208
  Working Capacity of 13
Hot Journals (*see* Coëfficient, Friction, Heat, Temperature).
Hughes, Resistance on English Tramways 15
Human Fat, Analysis of 61
Hydraulic Press Plunger, Friction of 37

Hydrometer 65-68
Ice, Friction of 28
Identification of Oil 60, 61
Ignition (*see* Burning, Combustion, Flashing, Fire Tests, Heat Temperature).
Illuminating Oil, Density 70
Impurities of Mineral Oils 80
India-rubber Belts 37
Ingham and Stapfer, Machine for Testing Lubricants 115
Iron Cast on Cast Iron, Friction of 26
    On Oak, Friction of 26
    On Leather, Friction of 26
Iron Cast Boxes and Wrought Iron Journals, Coefficient of Friction at Varying Velocities 183
    Brake Blocks, Friction on Steel Tires 32
    Journals, Lubricated with Commercial Oil 194, 195
    Journals, Steel Boxes, Lubricated with Sperm Oil 175
        do do do Lard Oil 175
        do do do W. Va. Oil 175
    Pulley and Leather Belts, Friction at Varying Velocities 183
    Wrought Brake Blocks, Friction 33
    •Friction of Journals 183
    Sliding Friction 26, 38
Jenkins and Ewing, Experiments on Friction, with Varying Velocities 184
Journals (*see* Coëfficient, Friction, Heat, Iron, Steel, Temperature)
    Friction, Nature of 18
    Locomotives 30
    Lubricated, Morin's Table 38
    Marine and Stationary Steam Engine 29
    Oiling of 57, 58
    Steel, with Bronze Boxes 185-187
    Steel, Coëfficient of Friction of 188
    Wrought Iron in Cast Iron Boxes 183
Kerosene Oil, Action of Acids 79, 95
    Density 69
    Friction 157
Kimball's Experiments 182-186
Laboratory, Mechanical, Stevens Institute of Technology—Record Blanks 139
Labrador Oil, Action of Acids 79, 95
    Density 69
    Cod Oil, Friction on Cast Iron Journals 157
Lake Shore & Michigan Southern Railroad, Machine for Testing Lubricants 119
    Tests of Endurance 153
Lampblack as a Lubricant 52
Lard Oil, Action of Acids 79, 95
    Analysis of 61
    Congelation Point 78, 153
    Density 69
    (Winter) Endurance 152, 153, 195, 196, 199
    Flashing and Burning Points 78
    Fluidity 89
    Friction on 156, 157, 175
    As a Lubricant 38
    Lubricating value of 152, 153
    Test of 163, 165, 171-175
    Value as a Lubricant 126, 127, 153

Viscosity ... 87, 153
Specific Gravity ... 153
Lead in Oils, Detection of ... 63
White, as a Lubricant ... 52
Leather on Cast Iron and Oak, Friction of ... 26
on Pine, Friction, with Varying Velocities ... 83
Lignum Vitæ, Friction on Pulleys ... 38
On Lignum Vitæ, Friction ... 38
Limestone on Brick, Friction ... 26
Linings of Bearings (*see* Bearings).
Linseed Oil, Action of Acids ... 79, 95-104
(Boiled), Cotton Waste Safurated by Temperature of Spontaneous Ignition and Combustion ... 80
Density ... 69
Friction ... 157
As a Lubricant ... 61
Viscosity ... 85, 87
Lubricants (*see* Coëfficient, Fluid, Friction, Greases, Heat, Journals, Oils, Tests, Unguents).
Commercial Value of ... 200
Density of ... 47
At High Temperature, Tests on Thurston's Lubricant Machine ... 138
Kinds in Use ... 47
Requirements of ... 44, 45
Solid ... 47
For Steam Cylinders, Tests on Thurston's Lubricant Machine ... 138
Uses of ... 43
Value of a ... 41, 45
What Determines their Values ... 44-46
Lubricating Machines for Testing (*see* Apparatus).
Quality, Tests on Thurston's Machine ... 136
Macadamized Roads (*see* Roads).
Machine (*see* Apparatus).
McNaught Machine, For Testing Lubricants ... 112
For Testing Lubricants, Hodgson's Modification ... 121
Maumene, Tests of Oils by Addition of Acids, and Noting Rise of Temperature ... 79, 80
Mecca (Black) **Oil,** Endurance ... 153
Action of Acids ... 79, 95
Density ... 69
Mechanical Laboratory of the Stevens Institute of Technology, Record Blanks ... 139
Menhaden Oil, Action of Acids ... 79, 95
Density ... 69
Mercury, Pernitrate of ... 92, 93, 102-104
Metalline ... 48, 52, 53
Metcalfe's Methods and Apparatus for Testing Lubricants ... 125-127
Mill Shafting, Friction of ... 46
Millspaugh, Fire Test, Apparatus for Oils ... 74
Mineral Oils, Action of Acids ... 79, 95
Adulteration of ... 80
Cotton Waste Saturated by, Temperature of Spontaneous Ignition and Combustion ... 80
Congelation Point ... 72, 78
Densities of ... 69, 70
Durability ... 152
Endurance of Cast Iron Journals ... 157
Fire Tests ... 72
Friction of ... 157

Fluidity of 80, 89
Impurities of 80
Lubricating Value of 152, 154, 155
Rise in Temperature by Friction 151
Minimum Friction, Temperature of 210
Mixtures of Oils 64
Moffat's Oleographic Tests 81
Morin's Experiments 16, 24, 26
Napier, Machine for Testing Lubricants 115
Napoli's Tests 151
Naptha, Action of Acids 79, 95
Density 69
Specific Gravity and Density 70
Temperature of Distillation 72
Nasmyth's Method of Determining Rate of Gumming and Viscosity. 85
Navy Yard, Brooklyn, Tests (*see* Brooklyn).
Neatsfoot Oil, Action of Acids 95-104
Density 69
Endurance of 153
Fluidity 89
Friction of 156, 157
Nitric Acid, Use in Tests 93
Nut Oil (Walnut), Action of Acids 95-104
Density 69
Oils (*see* Almond, Animal, Bank, Beech, Camline, Castor, Chloride, Chlorine, Cocoanut, Cod, Colza, Cotton Seed, Cylinder, Elaine, Engine, Fats, Fish, Grease, Hempseed, Horsefoot, Kerosene, Labrador, Lard, Mecca, Menhaden, Mineral, Naptha, Neatsfoot, Nut, Olive, Palm, Paraffine, Peanut, Petroleum, Porgy, Rapeseed, Ray, Red, Rhigoline, Rozin, Sea Elephant, Sesame, Shale, Sheepsfoot, Soda, Sperm, Tallow, Tanners', Vegetable, W. Va.).
Oils (*see* Chemical, Coëfficient, Congelation, Drying, Fire Test, Fixed, Friction, Gumming, Heat, Lubricant, Specific Gravity, Temperature, Viscosity).
Oil, Action of Acids 80, 95-104
Action of Metals 62, 63
Burning Points 45, 74, 76, 78
Chemical Tests of 89
Coëfficient of Expansion 68
Commercial, at Different Pressures—Thurston 194-196
Containing Copper, Detection of 63
Density 72
Effect of Heat 72
Electric Conductivity 72
Fire Tests 72
Flashing Points 45, 74, 76, 78
Compared with Grease as a Lubricant 40
How Fed 58
Identification of 60, 61
Impurities of 80
Mineral, Density 70
Mixtures of 64
Purification of 54
Temperature of Distillation 72
Temperature of Vaporization 72
Oiling Journals, Method of 58, 59
Olive Oil, Action of Acids 79, 95
Congelation 153

Density....... 69
Increase of Heat by Addition of Sulphuric Acid....... 79
Lubricating Value....... 152
Specific Gravity....... 153
Viscosity....... 153

Oleography....... 81

Oleomatry....... 65

"Palier-glissant" of Girard....... 68

Palm Oil, Action of Acids....... 79, 95
Density....... 69
Friction on Cast Iron Journals....... 157

Paraffine Oil, Action of Acids....... 79, 95
Density....... 70
Endurance....... 152, 153
Lubricating Value of....... 152

Pavements (*see* Roads).
Resistance of Vehicles on....... 11, 12, 16

Peanut Oil, Action of Acids....... 95–104
Density....... 69
Friction on Cast Iron Journals....... 157

Pernitrate of Mercury, Action on Oils....... 92, 93, 102–104

Petroleum Oil, Density....... 49, 50, 70
Endurance....... 152
Lubricating Value....... 152
Temperature of Distillation....... 72

Phosphoric Acid, Action on Oils....... 92, 93, 100, 101, 110

Pine on Pine, Coëfficient of Friction....... 26, 182, 183

Pistons of Pumps, Friction of....... 37

Plumbago, As a Lubricant....... 59
Grease, Endurance....... 195

Plungers of Hydraulic Press, Friction of....... 37

Poire, Adhesion of Locomotive Driving Wheels....... 39

Poppy Oil, Action of Acids....... 79, 95–104
Density....... 69
Increase of Heat by addition of Sulphuric Acid....... 79

Porgy Oil, Action of Acids....... 79, 95
Specific Gravity and Density....... 69

Potassa, Action upon Oils....... 93

Power (*see* Work, Horse).
Cost of with reference to Lubricants....... 201–204

Pressure, Admissible with different Lubricants....... 152–154
On Brake Block....... 33
Comparative, obtained with different Lubricants....... 152, 153
As affecting Friction....... 210
Friction with Varying....... 173
Influence upon Friction....... 10, 39
Limits of....... 56
Low, Coëfficient of Friction....... 156
Maximum on Rubbing Surfaces....... 55, 56
Relation between Pressure and Friction....... 174, 175
To Produce Skidded Wheels....... 37
and Speed Varying, Friction with....... 187
Speed and Temperature Varying, Friction with....... 187
and Temperature Varying, Friction....... 188
Temperature and Speed Varying, Friction....... 185–193
Velocity and Temperature Variable, Friction with....... 185–187
and Velocity Varying Simultaneously, Friction....... 187
on Unguents between Surfaces of Rest....... 34

Pullies of Cast Iron, Friction of Belts on....... 183

- **Pump Pistons,** Friction of........ 37
- **Purification of Oils**........ 54, 55
- **Purity of Oils,** To Determine........ 102–111
- **Quiescence or Starting,** Friction of..20, 24, 25, 27. 34, 178, 179, 206, 209
- **Rails,** Adhesion of Driving Wheels........ 29, 32
  - and Brakes, Friction of........ 29
  - Condition of Surface........ 30
- **Railroads** (*see* Adhesion, Axles, Cars, Wheels).
  - Trains, Coëfficients of Rolling Friction........ 16
  - Curves, Elevation of Outer Rail. Whinery........ 17
  - Train, Flange Resistance........ 14
  - Lubricant Machine. Thurston's........ 145
  - Trains, Resistance of Air........ 15
  - Train Resistances. Chanute's Analysis........ 17
  - Train Resistance. Clarke's Formula........ 15
  - Trains, Resistance of........ 13
  - Trains, Resistance on Curves........ 16
  - Trains, Rolling Resistance........ 11
- **Rankine,** Formula for Size of Journals for Locomotives........ 31
  - Friction on Belts........ 36
- **Rape Seed Oil,** Action of Acids........ 79, 95
  - Cotton Waste Saturated with Oils, Temperature of Spontaneous Ignition and Combustion........ 80
  - Density........ 69
  - Fluidity........ 89
  - Friction on Cast Iron Journals........ 157
  - Increase of Heat by addition of Sulphuric Acid........ 79, 80
  - Rise in Temperature by Friction........ 151
  - Viscosity........ 87
- **Ray Oil,** Action of Acids........ 100–104
  - Density........ 69
- **Reactions,** Chateau's General........ 91
  - Table of. Method of Using........ 105
  - Behren's........ 110
- **Reagents** (*see* Acid Chemical).
  - Use in Identification of Oils........ 60, 61, 94
- **Records,** Blanks for Lubrication Tests of the Mechanical Laboratory of the Stevens Institute of Technology........ 137
- **Red Oil,** Action of Acids........ 79, 95
  - Density........ 69
- **Red Saponified Oil,** Specific Gravity........ 92
- **Refining of Crude Cotton Seed Oil**........ 55
- **Rennie on Friction and Abrasion**........ 26
- **Repose,** Angle of........ 25
- **Researches,** Early........ 149
- **Rest** (*see* Quiescence).
- **Rhigoline Oil,** Action of Acids........ 79, 95
  - Density........ 70
- **Rigidity of Wire and Hempen Ropes**........ 18
- **Roads** (*see* Railroad).
  - Macadamized. Resistances of Vehicles........ 11, 12, 16
- **Rolling Friction,** Coëfficient for Metal........ 10
  - Coëfficient for Wood........ 9, 10
  - Coulomb's Experiments........ 9, 10
  - Morin's Experiments........
  - Laws of........ 9
  - Railroad Trains........ 15
- **Ropes** (*see* Belts, Cords, Pullies, Shears).
  - Friction on Pullies........ 36

Rozin Oil, Action of Acids 79, 95
  Coëfficient of Friction on 157
  Density 69
  Specific Gravity 69
Rubber Belting (*see* Belts).
Salad (Cotton Seed) Oil, Density 69
Sea Elephant Oil, Action of Acids 79, 95
  Density 69
Seal Oil, Action of Acids 95–104
  Density 69
  Fluidity 89
  Friction on Cast Iron Journals 157
Sesame Oil, Action of Acids 95–104
  Density 69
Shafting Mill, Friction of 40, 41
  Oiling of. Intermittent and Continuous 40
Shale Oil, Action of Acids 49, 79, 95
  Density 69
Shaw's Water Bearings 47
Sheepsfoot Oil, Action of Acids 96–104
  Density 69
Sheep's Fat, Analysis of 61
Size of Journals 56
Skates Steel, Friction of 29
Skidded Wheels, Friction of 30, 31, 33
Skids on Rails, Coëfficient of Friction 182
Sliding Friction 9, 20, 26
Soapstone as a Lubricant 52, 53
Society of Arts, Experiments on Resistances of Omnibuses 12
Soda Caustic in Lubricant Mixtures 50, 51
Soda Oil, Action of Acids 79, 95
  Density 69
Solid Lubricants (*see* Lubricants).
Specific Gravity of Lubricants 65, 68, 69, 70, 76
Speed (*see* Velocity).
Sperm Oil, Action of Acids 95–104
  Crossley's Apparatus for Testing 117
  Congelation 78, 153
  Density 69
  Endurance 153
  Flashing and Burning Points 78
  Fluidity 89
  Specific Gravity 153
  Rest of 162, 164, 171–175
  Value as a Lubricant 126, 127, 154, 155
  Viscosity of 85, 87, 153
Spindle Oils (Natural Summer and Winter Bleached), Coëfficient of Friction for Cast Iron Journals 156
Spontaneous Combustion, Temperature of 80
Starting (*see* Quiescence).
Steam Cylinder Lubrication 136
Steel Boxes and Cast Iron Journals, Friction 175
Steel, Friction of Abrasion 28
Steel Journals with Bronze Boxes, Friction 185–187
  Endurance of Oils on 196
  Friction of 174, 175, 188
Steel Skates, Friction of 29
Steel Tires, Friction of Brake Shoes 32, 33
Still Bottom, Impurities of Mineral Oils 80

- **Stillwell**, Determinations of Specific Gravity of Oils 68
- **Straits (Cod) Oil**, Density 69
- **Sulphur as a Lubricant** 56
- **Sulphuric Acid**, Action on Oils 79, 80, 90–110
- **Surfaces**, Condition of 208
  - Influence upon Angle of Repose 27
- **Tagliabue**, Fire Test Apparatus for Oils 73
- **Tallow**, Action on Acids 79, 95
  - Density 69
  - as a Lubricant, Value of 38, 50, 51, 152
- **Tallow Oil**, Action of Acids 95–104
  - Congelation of 153
  - Density 69
  - Durability 152, 153
  - Friction 156
  - Lubricating Value of 152, 153
  - Specific Gravity 153
  - Viscosity 153
- **Tanner's Cod Oil**, Action of Acids 79, 95
- **Temperature** (*see* Congelation, Heat, Fire Test).
  - of Bearings with Various Lubricants 151
  - on Bearings, Wheeldon, Coleman and Napoli's Experiments 150, 151
  - of Distillation 72
  - Effect on Friction 210
  - Journal as affecting Friction 210
  - of Lubricated Journals 159, 165
  - of Minimum Friction 190, 210
  - for Different Pressures and Speeds 185–193
  - Pressure and Speed Varying, Friction 187
  - Pressure and Velocity Varying. Table of Coëfficients 185
  - Speed and Pressure Varying, Friction 185, 193
  - Velocity and Pressure Variable, Friction 185–188
  - of Spontaneous Combustion 80
- **Testing** for Acids 63
  - for Adulterations 64
  - to Ascertain Name of Oil 105–108
  - to Ascertain Purity of Oil 109–111
  - for Copper 63
  - for Lead 63
  - Lubricants. Machines for (*see* Apparatus, Adulterations).
  - At Mechanical Laboratory of Stevens Institute of Technology 159–172
  - Of Oils. Facts to be Determined 59
  - Oleography 81
- **Tests** with Acid 79, 80
  - (*see* Bichloride).
  - of Chemical Methods 63, 64, 79, 80
  - for Cold (*see* Congelation).
  - of Drying 85
  - Durability of Lubricants (*see* Lubricants).
  - Effects of Heat (*see* Heat).
  - of Gumming 85
  - of Gumming of Lubricants (*see* Gumming).
  - of Lubricating Properties (*see* Lubrication).
- **Thermal Units**, British, French 42
- **Thurston**, Apparatus for Testing Lubricant 128, 145
  - Experiments, 128–143, 156–180, 185–196 87
  - Coëfficient of Friction on Cast Iron Journals 156, 157
  - Coëfficient of Friction on Fine Steel Journals, Varied Pressures 174
  - Coëfficient of Friction of Motion and Rest 175–177

- Coëfficient of Friction of Greases 157
- Coëfficient of Friction of Quiescence 178, 179
- Conclusions drawn from data obtained 208–212
- Details of Tests 159–173
- Endurance of Commercial Oils at Different Pressures 94–96
- Endurance of Lubricants 194–196
- Formula for Size of Journals 56, 57
- Friction, Sperm Oil, Steel Journals, Bronze Boxes, Velocity, Temperature and Pressure Variable 180, 187
- Low Pressures, Coëfficients 156
- Pressure and Temperature Variable, Steel Journals, Sperm Oil, Friction 188
- Railroad Testing Machine 145
- Viscosity of Oils 86, 87

Time of Contact, Influence of (*see* Quiescence).

Tin (*see* Bichloride).
- Action of Oils upon 63

Tires (*see* Wheels).
- Steel, Friction of Brake shoes 32, 33

Tomlinson's Oleographic Tests 81

Towne and Briggs, Friction on Belts 36, 37

Traction, Resistance 30

Tresca, Resistance of Vehicles 12

Unbleached Deodorized Lubricating Oil, Friction on 157

Unguents (*see* Lubrication).
- Classification of 61
- Characteristics of 43
- Effect of Heat upon 72
- Effect of Heavy Pressure with Surfaces at Rest 34
- Fatty, Classification of 61

Value of a Lubricant 45, 211
- Commercial of Lubricants 200 205, 211

Van Cleve's Tests of Lubricants 154, 155

Varying Pressure, Friction with 173
- Pressure, Speed and Temperature, Friction 85–193
- Speed and Pressure, Friction with 187
- Speed, Pressure and Temperature. Friction with 187
- Velocity, Friction with 180
- Velocity, Pressure and Temperature, Friction 185–188

Vaporization of Oils. Temperature of. Point of 72

Vegetable Oils, Action of Acids 79, 95
- Analyses of Chevreul and Braconnet 61
- Analysis of de Saussure 61
- Density 69
- Effect of Chloride upon 89

Vehicles, Resistance on Macadamized Roads 11, 12,
- Resistance on Roads 11, 12, 13

Velocity (*see* Speed).
- Influence on Friction 30, 32, 39, 209, 210
- Pressure and Temperature Varying, Table of Coëfficients 185
- Pressure and Temperature Variable, Friction with Sperm Oil, Steel Journals, Bronze Boxes. Thurston 185–187
- and Pressure Varying Simultaneously, Formula for Friction with Sperm Oil 187
- Varying, Coëfficient of Friction, Low Pressure and Slow Movements. Kunell 86
- (*see* Speed).

Viscosity of Oils, 153 (*see* Gumming).
- as affecting Endurance 197

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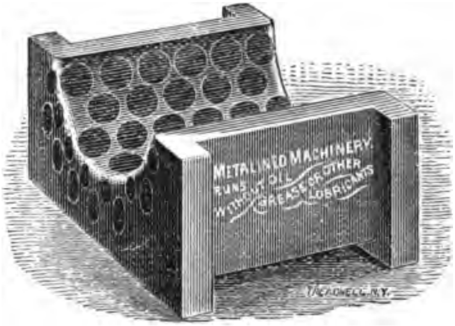
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